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Establishing Cost-Effective Safety Management for Major Oil and Gas Exploitation and Exploration Projects in the Design Phase

By

Roger Catchpole

**A thesis submitted in partial fulfillment of
the requirement of The Open University for
the degree of Doctor of Philosophy**

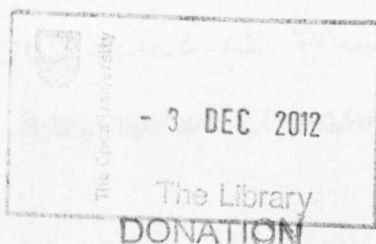
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ABSTRACT

Disasters such as Deepwater Horizon in the Gulf of Mexico, in April 2010, continue to blight the oil and gas industry despite a significant amount of research effort carried out by academia, regulatory bodies, and oil and gas companies to understand how safety-related incidents, especially disasters, can be prevented. While these have contributed to the discussion around reducing risk, they often lack the systemic influences that determine the value drivers affecting decision-making, and the ability to achieve continuous and sustainable improvements in safety performance. Consequently, this research aims to provide a more holistic approach to understanding the nature of disasters in the oil and gas industry, and identifying how future disasters can be prevented by establishing more cost-effective strategies. Quantitative research was carried out to determine the type and validity of the data used to construct trends in major accident safety performance, and qualitative research was carried out to assess the key factors that influence safety performance, and whether these are effectively applied. The conclusions of this research are that the industry has not demonstrated effective implementation of an Occupational Health and Safety Management System (OH&S-MS). Historically safety performance shows wide annual variations where trends are difficult to define and extrapolate, making it difficult to provide any significant benefit for major accident prevention. There is no evidence to indicate that moving from a prescriptive, to a goal-setting regime, has improved safety performance, and reduced the prospect of future major accidents. Disaster investigation reports have shown that the role of the regulator has been ineffective. However, the adoption of a more comprehensive, and effective approach to inherently safer designs, and the way projects are managed, have the potential to make safety management more cost-effective and reduce the prospect of future disasters.



DEDICATION

I would like to dedicate this thesis to my wife and children who provided support, especially during my periods of neglect, to allow me the time to complete this research.

ACKNOWLEDGEMENT

I would like to take this opportunity to thank all those people who offered their assistance encouragement and support throughout this study. In particular, I would like to express my sincerest appreciation to my supervisors, Drs Stephen Burnley and Suresh Nesaratnam, for their advice and unending patience and encouragement throughout; I am very grateful. I would also like to thank Dr Rod Barratt, who has since retired, but who helped instigate this project.

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STATEMENT OF ORIGINAL AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text

Roger Catchpole

June 2012

ABBREVIATIONS

ALARP	As low as is reasonably practicable
AIRMIC	The Association of Insurance and Risk Managers
API	American Petroleum Institute
ATG	Automatic tank gauging
bbl	One barrel of oil; 1 barrel = 35 Imperial gallons (approx.), or 159 litres (approx.); 7.5 barrels = 1 tonne (approx.); 6.29 barrels = 1 cubic metre
bcf	Billion cubic feet; 1 bcf = 0.83 million tonnes of oil equivalent
bcm	Billion cubic metres (1 cubic metre = 35.31 cubic feet)
BDV	Blowdown valve
BOP	Blowout preventer
BP	British Petroleum
BPA	British Pipeline Agency
BS	British Standard
CAPEX	Capital expenditure
CBA	Cost Benefit Analysis
CER	Commission for Energy Regulation
CIMAH	Control of Industrial Major Accident Hazards
COMAH	Control of Major Accident Hazards
DAFWCF	Days Away From Work Case Frequency
DART	Days Away from Work or Restricted Time
DRM	Disaster Reduction Management
COINS	Combined Online Information System
CRINE	Cost Reduction Initiative for the New Era
DHSV	Down-hole safety valve
E&A	Exploration and appraisal
E&P	Exploration and production
ESDV	Emergency shutdown valve

ESSA	Eliminate, Simplify, Standardise, Automate
ESSA	Emergency Systems Survivability Analysis
EU	European Union
FAR	Fatal Accident Rate
FCB	Faster, Cheaper, Better
FIR	Fatal Incident Rate
FSF	Flight Safety Foundation
FSU	Former Soviet Union
FMEA	Failure Modes and Effects Analysis
G	Gas
G/C	Gas/Condensate
GAIN	Global Aviation Information Network
GHSER	Getting Health, Safety, and the Environment Right
GoM	Gulf of Mexico
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HCR	Hydrocarbon Releases
HES	Health, environment and safety
HFE	Human Factors Engineering
HOSL	Hertfordshire Oil Storage Ltd
HRO	High Reliability Organisation
IADC	International Association of Drilling Contractors
ICAF	Implied Cost to Avert a Fatality
ICAO	International Civil Aviation Organisation
IEC	International Electrotechnical Commission
IHLS	Independent high-level switch
INPO	Institute of Nuclear Power Operations
IOM	Institute of Medicine

IRPA	Individual Risk Per Annum
IRM	Institute of Risk Management
ISD	Inherently Safer Design
ISO	International Standards Organisation
ISOM	Isomerization
KPI	Key Performance Indicator
LOPA	Layers of Protection Analysis
LSR	Life Saving Rules
LTI	Lost Time Injury
LTIF	Lost Time Injury Frequency
LTIR	Lost Time Injury Rate
mboe	Million Barrels Oil Equivalent
mmcfd	Millions of cubic feet per day (of gas)
Mt	Million tonnes
MAHB	Major Accident and Hazards Bureau
MAUA	Multi-Attribute Utility Analysis
MMS	Minerals Management Service (later to become The Bureau of Ocean Energy Management, Regulation and Enforcement) which then, in October 2011 became two bodies – the Bureau of Ocean Energy Management and the Bureau of Safety and Environmental Enforcement
MoC	Management of Change
MOL	Main Oil Line
MTC	Medical Treatment Case
NASA	National Aeronautics and Space Administration
NAT	Normal Accident Theory
NCS	Norwegian continental shelf
NGLs	Natural gas liquids (Liquid hydrocarbons found in association with natural gas)
NGO	Non-Governmental Organisation
NPV	Net Present Value

NRC	Nuclear Regulatory Commission
NSOAF0	North Sea Offshore Authorities Forum
NTSB	National Transport Safety Board
OPEX	Operating expenditure
OCS	Outer Continental Shelf
OECD	Organisation for Economic Co-operation and Development
OGP	Oil and Gas Producers
OH&S-MS	Occupational Health and Safety Management System
OpCo	Operating Company
ONS	Offshore North Sea
OREDA	Offshore Reliability Data
OSHA	Occupational Safety and Health Administration
POB	Persons on Board
PPE	Personal Protective Equipment
PQV	Programme Quality Verification
PSA	Petroleum Safety Authority [Norway]
PSM	Process Safety Metrics
PSSR	Pre-Startup Safety Review
PSV	Pressure safety valve
QRA	Quantitative risk analysis
RAM	Risk Assessment Matrix
RNNP	Trends in risk level [in Norwegian petroleum industry]
RoSPA	Royal Society for the Prevention of Accidents
RWC	Restricted Workday Case (or RWDC)
SDO	Standards Development Organisation
SEMS	Safety and Environmental Management System
SEP	Special Emphasis Program

SFAIRP	So Far as is Reasonably Practicable
SINTEF	Stiftelsen for industriell og teknisk forskning (The Foundation for Scientific and Industrial Research) in Norway
SMS	Safety Management System
SSIV	Subsea Isolation Valve
STOP	Safety Training Observation Programme
tcf	Trillion Cubic Feet (of gas)
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TLC	Total Loss Control
TQM	Total Quality Management
TRCF	Total Recordable Case Frequency
TRIR	Total Recordable Incident Rate
TSR	Temporary Safe Refuge
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
UK HSE	United Kingdom Health and Safety Executive
UKOOA	United Kingdom Offshore Operators Association
UKOP	UK Oil Pipelines Ltd
ULC	Ultracracker unit
VPP	Voluntary Protection Programme
WOAD	World Offshore Accident Database

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1. INTRODUCTION TO THE RESEARCH

1.1 Introduction

The global oil and gas industry has experienced a number of disasters with loss of life, large financial losses and, in some cases, huge environmental impacts. The actual final costs of major accidents are very rarely made public. They are difficult to quantify, as companies may report their losses differently, and they may be too complex to provide final amounts due to the combination of direct and indirect costs, and long term liabilities [1]. However, the European Commission (EC) estimates the annual average cost of all major accidents, including those in the non-oil and gas sector, to be between £171 million and £764 million [2]. Data is available that illustrates the general costs of accidents, and the associated adverse impact on society, employers and employees, for UK general workplace injuries and illnesses [3]. For example, the annual cost, based on 2009/2010 data, and 2009 prices, is estimated at £14 billion. This comprises an estimated 700,000 workplace injuries, 166 fatalities, and 500,000 work-related illnesses, Table 1 [4].

Table 1 Average Cost of UK Accidents per Case

Category ¹	Event	Total Cost in £s (rounded) ^{2 3}
Costs to Society per Case	Workplace fatality	1,502,000
	Reportable incidents	17,400
	Minor injuries	290
	Ill health	16,100
Costs to Individuals per Case	Workplace fatality	1,221,000
	Reportable incidents	10,900
	Minor injuries	50
	Ill health	8,000
Costs to Employers per Case	Workplace fatality	160,000
	Reportable incidents	3,100
	Minor injuries	30
	Ill health	4,000
Costs to Government per Case	Workplace fatality	120,000
	Reportable incidents	3,400
	Minor injuries	210
	Ill health	4,100

¹ Based on the reporting requirements of the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR).

² Not comparable with previous estimates as new costing methodology applied

³ Total costs comprise non-financial human costs (an estimate of the monetary values that individuals would be willing to pay to avoid risk of death or ill health or injury) and direct financial costs

More than two years after the Deepwater Horizon disaster (June 2012) the costs are still ongoing and British Petroleum's (BP's) accounts for 2010 show that they put aside \$41bn to pay for the spill, which is more than two and a half times BP's entire profit in 2009 [5, 6]. In the UK sector of the North Sea the first disaster of note, the Sea Gem disaster, occurred in 1965. Details of this disaster are given below, but, as demonstrated by the Deepwater Horizon disaster in 2010, the global oil and gas industry is still not immune from major accidents. This history is illustrated below by a small sample of disasters, which occurred between 1965 and 2010.

Figure 1 Sea Gem

(Source: Derek Park, Never say never again, Oil and Gas iQ)



On 27 December 1965, the drilling rig (see Glossary) Sea Gem (Figure 1) was located approximately 67 kilometres off the coast of Lincolnshire. The crew were in the process of moving the rig to another site approximately two nautical miles away, when two of the legs crumpled and broke, causing the rig to capsize and equipment and people to slide off into the freezing cold of the North Sea. Altogether, 13 men lost their lives and five were injured [7].

Figure 2 Alexander Kielland

(Source: Derek Park, Never say never again, Oil and Gas iQ)



In March 1980, Alexander L. Kielland (Figure 2), a Norwegian semi-submersible drilling rig, capsized whilst working in the Ekofisk oil field killing, 123 people. The capsizing was the worst disaster in Norwegian waters since World War II. The rig was located approximately 320 km east of Dundee, Scotland [8].

Figure 3 Ocean Ranger

(Source: Derek Park, Never say never again, Oil and Gas iQ)



when it sank. There were no survivors of the accident [9].

On 15 February 1982 Ocean Ranger, a semi-submersible mobile offshore drilling unit, sank in Canadian waters. It was drilling an exploration well in the Grand Banks area, 267 kilometres east of St. John's, Newfoundland, for Mobil Oil of Canada with 84 crew members on board

Figure 4 Piper Alpha before the disaster

(Source: Picture Piper Alpha, Google Images)



On 6 July 1988, Piper Alpha (Figure 4 and Figure 5), a North Sea oil production platform operated by Occidental Petroleum (Caledonia) Ltd, experienced explosions and fires that destroyed the platform, killing 167 men, with only 61 survivors. The total insured loss was about £1.7 billion (US\$3.4 billion).

Figure 5 Piper Alpha during the disaster

(Source: Derek Park, Never say never again, Oil and Gas iQ)



offshore installation. At the time of the disaster the platform accounted for approximately ten percent of North Sea oil and gas production [10].

The accident was instrumental in bringing about the Offshore Installations (Safety Case) Regulations. A safety case is a written document in which a company must demonstrate that an effective safety management system (SMS) is in place on a particular

Figure 6 Petrobras 36

(Source: Derek Park, Never say never again, Oil and Gas iQ)



In the early hours of March 15, 2001 there were two explosions onboard the Petrobras 36 (P-36) (Figure 6). The first explosion was caused by an overpressure event, the second by ignition of leaking hydrocarbon vapour. At the time there were 175 people on the rig; 11 were killed. Petrobras 36 (P-36) was the largest

floating semi-submersible oil platform in the world prior to its sinking on 20 March 2001 [11].

Figure 7 West Atlas

(Source: Derek Park, Never say never again, Oil and Gas iQ)



In August 2009, there was a blowout and fire (Figure 7) on a wellhead platform in the Montara field off Western Australia. The cantilever jackup West Atlas was operating over an adjacent well at the time and all 69 workers were safely evacuated.

The well was eventually killed after leaking for 74 days. It is considered to be one of Australia's worst oil disasters. The West Atlas rig was owned by the Norwegian-Bermudan company Seadrill, and operated by PTTEP Australasia (PTTEPAA), a subsidiary of PTT Exploration and Production (PTTEP). Houston-based Halliburton was involved in cementing the well. The Montara field is located off the Kimberley coast, 250 north of Truscott airbase, and 690 kilometres west of Darwin [12].

Figure 8 Deepwater Horizon

(Source: Derek Park, Never say never again, Oil and Gas IQ)



On 20 April 2010, while drilling at the Macondo Prospect, the Deepwater Horizon drilling rig experienced an explosion caused by a blowout which killed 11 crewmen and ignited a fireball visible from 35 miles away. The resulting fire could not be extinguished and, on 22 April 2010, Deepwater

Horizon sank, leaving the well gushing at the seabed and causing the largest offshore oil spill in U.S. history. Deepwater Horizon was an ultra-deepwater, dynamically positioned, semi-submersible offshore oil drilling rig owned by Transocean.

On Sunday 25th March 2012, Total lost control of a well in the Elgin-Franklin field, 240km east of Aberdeen. The installation was evacuated before any lives were lost but current estimates are that the major accident will cost the French group billions of dollars in lost revenue and associated costs. As yet (June 2012), the causes of the accident, and the means of regaining well control have not been identified. Consequently the installation remains shutdown and unmanned [13].

Advanced systems played a key role in the rig's operation, from pressure and drill monitoring technology, to automated shutoff systems and modeling systems for cementing. Litigation, the ultimate assessment of damage and the scope of final insurance recovery are all unknown at present, i.e. 2012. However, analysts report that the aftermath is of unprecedented scale and complexity compared to previous disasters which themselves took many years to resolve, Figure 8, [6].

The seven disasters described above, spanning 45 years to 2010, resulted in the loss of 409 lives and yet represent only a small fraction of the number of lives lost in oil and gas operations globally during that period. So, are these disasters simply random, infrequent events that were impossible to predict, or were they reasonably foreseeable and therefore should have been

prevented? In this thesis it is reasoned that the historical and current approach to safety management in the oil and gas industry is ineffective and that significant change is required to make continuous and sustainable improvements in safety performance. If the oil and gas industry fails to make this transition, it is likely to continue to experience major accidents, such as those described above. Furthermore, the ability of the oil and gas industry to prevent future disasters is further exacerbated by the current (2012) challenges facing the industry, such as:

- moving from mature assets in politically and economically stable environments to less stable operating environments such as Nigeria, Russia and the Former Soviet Union (FSUs) states;
- more demanding locations, both geographically and technically, such as the Arctic, deepwater areas, including the Gulf of Mexico, and the severe environmental conditions in the Caspian Sea in Kazakhstan, Central Asia;
- greater competition from within the industry and externally from sources such as renewable energy supplies and nuclear energy;
- the continued volatility of the oil price (often linked to the gas price); and
- maintaining or improving margins by minimising costs and maximising production (revenue).

Consequently, the combination of the above factors, and other internal (e.g. shareholder) and external influences (e.g. regulatory authorities) warrant changes to make safety management more effective.

1.2 The future of the oil and gas industry

It can be said that oil and gas exploration and exploitation is essential to continued economic growth, particularly in developing countries [14]. The economic, geographical and political environments, in which future oil and gas exploration and exploitation are necessary, present significant challenges to companies.

In addition, often, due to the complexity of remaining reservoir characteristics, the technical challenges can generate much higher risks when working in these locations compared to previous developments. In search of oil and gas, many companies have become multinational in order to satisfy global demand for growth and to acquire adequate reserves of hydrocarbons. Shell and BP, in particular, have historically been seen to be relatively successful when measured by various financial criteria in comparison with other multinational organisations, although, since the Deepwater Horizon disaster in 2010, BP's reputation and financial status has been severely adversely impacted. Generally, the financial success of oil and gas companies is mainly achieved through managing margins, e.g. maximising production and minimising costs, as suggested by a BP Amoco financial and competitive strategy case study [15]. These two factors are always likely to have a significant weighting in comparison with other business objectives, such as safety performance, especially when shareholder value is often about short-term profit maximisation in an environment where there is always considerable uncertainty about the future oil price (Oil price is considered relatively synonymous with gas price in this research) [16].

Nevertheless, under UK legislation, organisations, rather than individuals, are still primarily responsible and accountable for the management of safety, and in support of their legal obligations, generally implement a safety management system (SMS) to help achieve safety objectives.

While the SMS (referring to an Occupational Health and Safety Management System, OH&S-MS, in this research) provides the theoretical framework for effective safety management, it does not, for example, identify how the management of resources, e.g. time, money, effort, is administered to achieve safety performance objectives. Resource allocation is often commensurate with the level of safety performance an organisation aspires to, and is generally dependent on various factors, such as the financial margin being targeted by an organisation, and the level of regulatory compliance and safety culture.

This should be seen in a context where multinational oil and gas organisations work in a dynamic operating environment undergoing constant change, e.g. due to the cyclical oil price and varying unit costs of production, legislation from prescriptive to goal-setting, and cultural changes relating to the organisation (people and competencies, etc.).

1.3 Inherent hazards in oil and gas exploration and exploitation

However, irrespective of the changes that influence organisational behaviour, the industry has inherent major hazards, e.g. hydrocarbons under pressure that it cannot eliminate and has to manage. Therefore organisations, including oil and gas companies, which are responsible for the creation of major hazards are required to implement controls to reduce both the likelihood and consequences of a failure, e.g. to reduce residual risk to a level that is both tolerable and as low as reasonably practicable (ALARP) [17]. ALARP is a concept applied in UK safety legislation and often used globally by oil and gas companies with international operations. However, achieving ALARP is generally subjective, and therefore oil and gas companies, particularly in a goal-setting legislative regime, have significant freedom to decide the level of safety-related risk they are prepared to tolerate to achieve their overall business objectives.

1.4 Safety Performance

At a global level the industry has relied on the voluntary but often restricted disclosure of incident information that is generally dominated by reactive criteria to provide safety performance data and allow the industry to benchmark performance. This has limited benefit, and arguably, can be misleading, to the extent that it might suggest a safety performance which is better than actually achieved, as demonstrated by the Texas City [2005] [19] and Deepwater Horizon disaster investigation reports [6, 20]. This can have the effect of reducing the resources allocated to making improvements in safety performance, and/or the ineffective use of limited organisational resources by targeting safety improvement strategies that yield little value.

It is evident from four case studies (Piper Alpha (1988), Texas City (2005), Buncefield (2005) and Deepwater Horizon (2010) [6, 10, 18, 21]) that safety has been significantly compromised despite the fact that Texas City and Buncefield occurred about 17 years after Piper Alpha, and Deepwater Horizon 22 years post-Piper Alpha. In all four cases there is evidence that when the culture of maximising margins becomes too dominant, safety performance is often sacrificed.

Furthermore, as demonstrated in Chapter 5, analysis of the global industry safety performance also suggests that these events are not random, but indicate an endemic failure within the oil and gas industry to achieve continuous and sustainable improvements in safety performance.

1.5 Purpose of this Research

A significant amount of research effort has been carried out by academia, regulatory bodies, and oil and gas companies to understand how safety-related incidents, especially disasters, can be prevented. While significant authoritative work has been published, particularly post-Piper Alpha, and is available in the public domain, disasters such as Deepwater Horizon continue to blight the industry. However, much of the previous research has been relatively esoteric and discipline-based, e.g. human factors, fuzzy logic, computational fluid dynamics, etc.

While these studies have contributed to the discussion around reducing risk, they often lack the systemic influences that determine the value drivers affecting decision-making, and the ability to achieve continuous and sustainable improvements in safety performance. Consequently, this research aims to provide a more holistic approach to understanding the nature of disasters in the oil and gas industry, and to identify how future disasters can be prevented by establishing more cost-effective strategies.

As oil and gas companies face significant technical, economic and safety challenges, the management of safety has to be shown to be cost-effective in order to maximise its value in the context of limited resources. Cost-effectiveness can be described as *'being effective without wasting time or effort or expense [22]'*.

1.6 Hypotheses

The hypotheses are that:

- the global oil and gas industry has not achieved continuous and sustainable improvements in safety performance and consequently remains vulnerable to future major accidents;
- effective implementation of Occupational Health and Safety Management Systems is compromised by management factors, such as maximising financial margins and poor safety culture;
- the methods and criteria used by the industry to measure and publish safety performance yields are of limited value and may inhibit improvement in safety performance; regulators have been ineffective in their role to support the industry to reduce work-related death and serious injury; and
- The industry is not robustly capturing lessons learnt from previous disasters and therefore is liable to repeat them in the future.

In this research the emphasis relates to the safety component of an OH&S-MS, but since there are various synergies between improvements in any one, or combination, of health, safety and the environment, the term OH&S will continue to be applied. It is argued that if the current approach to OH&S is continued, in combination with the predicted development challenges, it is extremely unlikely that safety performance will achieve continuous and sustainable improvements that might prevent, or reduce the frequency of, future major accidents. Therefore, a different approach to OH&S management is required.

The aim, and motivation for the research, is to identify how the industry can achieve continuous and sustainable improvements in occupational health and safety to reduce the number of major accidents and, by implication, the number of fatalities and serious injuries within the oil and gas industry.

Other than the moral or ethical factors driving this objective, it would be of significant benefit to the industry if it can reduce its costs by implementing a more cost-effective system for managing safety. This could help extend the life of the industry when it is becoming more vulnerable to competition, both from within, and externally.

In the general context of the global oil and gas exploration and exploitation industry, the research objectives are to:-

- Assess those management factors that might have an impact on the ability to deliver OH&S objectives. This includes the scope and role of an OH&S-MS in managing risk. In most countries there is already a legal framework that requires organisations to manage activities to prevent harm to people. An OH&S-MS seeks to supplement the legal requirements by providing guidance on how the management of safety can be integrated with the management of other business objectives to minimise risk, improve business performance and establish a responsible image in the marketplace;
- Evaluate the role of safety legislation and the safety regulator as it is often assumed that the role of regulatory agencies is simply to bring about compliance with regulation. However, they are also required to encourage improvements in safety performance;
- Consider typical hazards and ascertain how the industry currently approaches safety [risk] management, during the lifecycle of a typical development. In particular, examining when decisions should be made to cost-effectively achieve safety goals over the lifecycle of a development;
- Examine the industry's historical safety performance to assess whether it can demonstrate a continuous and sustainable safety performance;
- Review relatively new concepts of inherent safety, high reliability organisations, resilience engineering and human factors to assess their potential value in meeting industry safety objectives, and how well they have been implemented by the industry; and

- Review selected disaster case studies which have occurred over a suitable period, that should have allowed lessons learnt to be embedded in industry hazard management systems and prevent future disasters.

1.7 Importance of the study

Four disasters, described more fully later, have been evaluated and compared to assess whether the lessons that should have been learnt were adequately captured and could have prevented further disasters. The Piper Alpha disaster where 167 personnel died occurred in 1988. The second disaster, Texas City occurred in 2005, and 15 people died. The third, at Buncefield, occurred in 2005; there were no fatalities but the economic cost was huge, given the damage to the site and its surroundings, and the disruption to transportation and businesses in the area. The fourth, the Deepwater Horizon disaster, occurred in 2010, and 11 people died.

These types of disaster are often quoted as being rare and random events, and by implication, unpredictable or unforeseeable. Therefore, the conventional view is that there is very little that can be done to prevent them. This research examines this theory to determine whether they can be predicted and therefore prevented. This would save lives, improve financial performance and enhance reputations.

1.8 Scope of the research

The study primarily covers the safety performance of the upstream (exploration and exploitation) operations, as opposed to downstream (comprising refining and marketing) activities. Within the context of upstream operations the research has a global dimension, but focuses on offshore activities, since:

- many of the major accidents in the oil and gas industry have occurred in the offshore sector; and
- the design, installation, commissioning, operation, maintenance and abandonment of offshore facilities is generally more challenging than for onshore facilities.

The research is also focused on UK oil and gas activities since the global industry tends to use the UK as a benchmark for safety management.

Safety can be assessed through major accident hazards or occupational hazards (the difference being the severity of the outcome of failure and the number of people affected). This ignores the implications of asset damage, environmental impacts and reputational issues. This research focuses on major accident hazards since it is argued they are a symptom of a wide catalogue of failures but with greater single event consequences. Finally, the focus of the research relates to the design phase of oil and gas facilities, on the premise that it is this stage that largely governs, from a major accident hazard perspective, the safety performance of the facility during its remaining lifecycle phases.

Also, it is at this stage that the most cost-effective decision making occurs, as subsequent changes in design are likely to be of comparably higher cost.

1.9 Limitations of this research

The advantages and disadvantages of goal-setting compared with a more prescriptive approach are not the specific subject of this research, as arguably, the organisations that have inherent hazards have an ethical responsibility to employees and the public (society) to manage their residual risks to levels that are socially acceptable, irrespective of the legislative regime. Therefore, in this model, legislation should only be applied where this responsibility is unlikely to be properly discharged. The potential impact of organisational change, such as 'right-sizing' is also not considered in depth, since one of the goals of private enterprise is to analyse market mechanisms that establish relative prices amongst goods and services, and allocate limited and often competing resources amongst many alternative uses. Resources, in this context, include labour, but are representative of other costs of production.

The commercial conditions in which oil and gas prices are set are not considered in depth other than the impact price decisions might have on the safety performance of the industry.

There is an underlying assumption that all incidents and accidents, whether major or minor, can be prevented. In theory this may be true. In practice, the problem of obtaining zero incidents or accidents on a sustainable basis is extremely difficult, and some might say impossible or impracticable. However, it is considered that there is a moral imperative that organisations should seek to achieve zero accidents. Consequently, this research takes the view that all incidents are preventable.

1.10 Summary

Despite decades of global oil and gas exploration and exploitation, the oil and gas industry still experiences disasters that affect both employees and the public. Globally fossil fuels are still necessary for economic growth, and demand remains an important part of the global energy portfolio in energy markets. However, there are inherent hazards associated with oil and gas activities that cannot be eliminated and this presents a constant threat to people who are directly or indirectly affected by these operations. To date it is argued that the industry remains as vulnerable to a major accident as it did several decades ago.

Consequently, this research aims to understand the factors that influence safety performance in order to assess whether change is needed to deliver more continuous and sustainable safety improvements, particularly in preventing major accidents. The recent, 2010, Deepwater Horizon disaster in the Gulf of Mexico illustrates the importance of this research.

The research will primarily cover global upstream oil and gas operations but is more focused on oil and gas operations in the offshore UK sector of the North Sea, as this tends to provide a benchmark to the industry in terms of safety management. There are limitations to the research, perhaps the most important being the assumption that all incidents can be prevented.

2. TRADITIONAL OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEMS

2.1 Introduction

This section covers:

- management factors that influence safety performance. This includes Occupational Health and Safety Management Systems (2.2) and Margins, Profits and Resources Allocation;
- a review of the role of UK safety legislation and the Regulator;
- the factors that guide project and risk management, particularly during the design phase ;
- major accidents and how the industry measures safety performance and its implications; and
- a review of recent theories and concepts influencing safety management.

The aim of the review is to capture as much as possible of the existing relevant literature on oil and gas industry safety management, including safety-related internationally-recognised codes and standards, and relevant legislation. Much of the material is 'published' work, defined as: all papers or articles of an academic, professional or general nature, published for a wide readership, and has three principal aims:

- To introduce a broad or general background to the subject matter in terms of reading and consultation.
- To assist in the acquisition of general and specific knowledge relevant to the subject matter being researched.
- To assist in formulating and developing a broadly-based research framework, and model, upon which a sound research methodology could be based [23].

2.2 Occupational Health & Safety Management Systems (OH&S-MSs)

2.2.1 Systems and processes

Management system literature reveals many different definitions of a system; such as:

- Reactive systems, e.g. air conditioning;
- Responsive systems, e.g. computers; and
- Purposeful systems that choose their goals and adapt to their environment.

In this context, an OH&S-MS is seen as a purposeful system that with the help of people, determines the mission from analysis of stakeholder needs, adapts to its operating environment, and enables the organisation to deliver goals that satisfy its stakeholders. There are many different definitions of a process but the key features are that a process transforms inputs into outputs, to achieve some desired results [24].

2.2.2 OH&S-MSs

Global offshore production of oil and gas is technically and financially challenging, but is essential as part of an overall global energy portfolio, to sustain economic growth in the industrialised world and for future growth in developing countries [14, 25]. However, while there are potential benefits from oil and gas production, there are also significant risks, such as those associated with hostile operating climates, and the technological complexities of the structures and organisations required to safely, and economically, recover these reserves [26]. These risks have been demonstrated by disasters shown in the Introduction to this research.

In a report published 20 years after Piper Alpha, the International Association of Oil and Gas Producers (OGP) [27] made a number of important observations with respect to OH&S-MSs including:

- *“Incidents such as Alexander Kielland and Piper Alpha occurred at a time when the importance of having in place an integrated and robust SMS was still relatively unappreciated”.*

- *“Following disasters such as Alexander Kielland and Piper Alpha, the majority, if not all, Exploration and Production (E&P) organisations operate an OH&S-MS based on internationally recognised standards and guidelines”.*
- *“A functional OH&S-MS should provide the framework within which all significant hazards are identified and measures put in place to manage the risks they pose. Hence, theoretically at least, the management of major incident risks (arguably all OH&S risks) requires little more than the appropriate application of the risk assessment tools and management processes implicit within any exploration and production (E&P) relevant Safety Management System (SMS)”.*

OGP then state, *“While certain major incidents that have occurred within the E&P industry suggest a failure to put in place the basics of an adequate OH&S-MS (or parts of it) many others point towards the challenges of applying such systems to low frequency, complicated failure scenarios, where, on occasion, the hazard or risks may not be recognised”.*

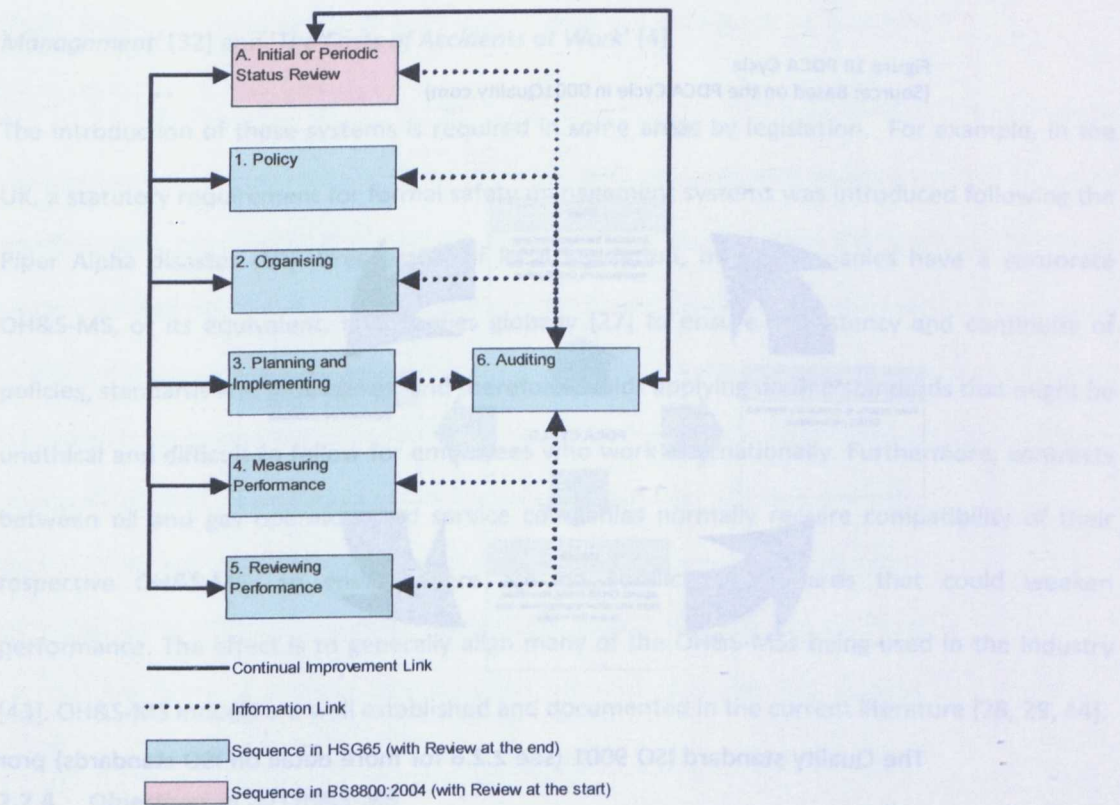
2.2.3 The Role of the OH&S-MS

A management system can be defined as a system to establish policy and objectives, and provides the framework to achieve those objectives [28, 29].

The principles of a management system are similar for quality [30], environment [31] and OH&S, with continuous improvement being a key goal. For example, HSG 65 (Successful Health and Safety Management) was prepared by the UK HSE's Accident Prevention Advisory Unit (now Operations Unit) in 1991, as a practical guide for directors, managers, health and safety professionals and employees [32]. It is aimed at those who want to improve health and safety in their organisations and states that, *“organisations need to manage health and safety with the same degree of expertise and to the same standards as other core business activities, if they are effectively to control risks and prevent harm to people”.*

Consequently, OH&S-MSs should be designed to provide continuity with a consistent and structured approach to identifying improvement opportunities, and are used to demonstrate that adequate controls are in place to provide suitable and sufficient management of risks. The key features of an OH&S-MS are illustrated in Figure 9.

Figure 9 Key Features of an OHS-MS
(Source: Based on HSG 65 and BS 8800:2004)



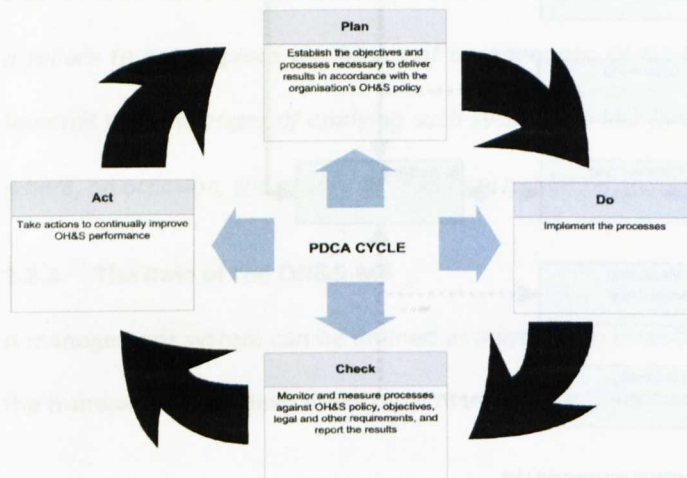
An OH&S-MS describes the way an organisation is managed to enable it to meet its safety objectives. However, in the oil and gas industry, there appears to be conflicting evidence about whether OH&S-MSs are achieving their intended objectives, either in terms of reducing numbers of incidents and/or the rate at which improvement is taking place, or the reduction in the severity of the incidents, e.g. major accidents [33].

The general characteristics of an OH&S-MS include a basic 'plan', 'do', 'check' and 'act' (PDCA) loop (Figure 10) and this approach has generally been applied by the oil and gas industry since, at least, the early 1990s [27].

Many organisations manage their operations with the application of a system of inter-related resources and activities which transform inputs into outputs, and which can be referred to as the 'process approach'[34]. Processes in an organisation are generally planned and carried out under controlled conditions to add value.

Figure 10 PDCA Cycle

(Source: Based on the PDCA Cycle in 9001Quality.com)



The Quality standard ISO 9001 (see 2.2.6 for more detail on ISO standards) promotes the use of the process approach when developing, implementing and improving the effectiveness of a quality system. Indeed an OH&S management system can enhance customer satisfaction by meeting customer requirements [35]. In this context, customers can refer to internal members of the organisation as well as external customers.

The OH&S-MS is considered to be part of an organisation's [overall] management system used to develop and implement its OH&S policy and manage its OH&S risks.

Therefore, it should include organisational structure, planning activities (for example, risk assessment and the setting of objectives), responsibilities, practices, procedures, processes and resources [28].

The importance of an OH&S-MS has been identified in a number of reports including the Flixborough [36] and Piper Alpha [10] disasters, and by the UK HSE in a number of their publications, such as *'Success and Failure in Accident Prevention'* [37], *'Managing Health and Safety'* [38-41], *'Effective Policies for Health and Safety'* [42], *'Successful Health and Safety Management'* [32] and *'The Costs of Accidents at Work'* [4].

The introduction of these systems is required in some areas by legislation. For example, in the UK, a statutory requirement for formal safety management systems was introduced following the Piper Alpha disaster [10]. Irrespective of local legislation, many companies have a corporate OH&S-MS, or its equivalent, that applies globally [27] to ensure consistency and continuity of policies, standards and procedures, and therefore avoids applying double standards that might be unethical and difficult to follow for employees who work internationally. Furthermore, contracts between oil and gas operators and service companies normally require compatibility of their respective OH&S-MSs to ensure there are no conflicting standards that could weaken performance. The effect is to generally align many of the OH&S-MSs being used in the industry [43]. OH&S-MS models are well established and documented in the current literature [28, 29, 44].

2.2.4 Objectives of an OH&S-MS

The primary aim of an OH&S-MS is to protect people. To achieve this, companies are required to develop, implement, maintain and record OH&S objectives for all relevant departments within the organisation. The objectives must be measurable and support the OH&S policy (particularly those aspects associated with the commitment to prevent injury and ill health) and comply with legislation and the process of continual improvement.

The objectives should also consider the nature of the organisation's risks, together with its technological, financial, operational and business requirements and the views of its stakeholders. BS OHSAS 18001:2007 [28] defines OH&S objectives as the, *"goal, in terms of OH&S performance, that an organisation sets itself to achieve"*. However, a crucial and often unanswered question is, 'to what degree must people be protected'? Therefore, by implication, what constitutes a successful OH&S-MS? In this context there are two factors to be considered; one is the absolute requirement to prevent all injuries and ill health. This has to be an organisation's primary objective as it satisfies the moral imperative that underpins BS OHSAS 18001:2007, etc. The second factor is to achieve a tolerable level of risk, to as low as is reasonably practicable (ALARP).

The use of risk recognises that there are inherent hazards in most, if not all, work environments, and that to achieve, on a sustainable basis, zero accidents or instances of ill health, is extremely complex. Particularly, in the case of health, there is often a significant period between exposure to a hazardous substance and the onset of symptoms. This is particularly relevant, but not unique, to the oil and gas industry given, for example, the geographical and cultural diversity in its activities, and the complex techniques and technologies required to explore for and exploit hydrocarbons. However, a fundamental principle underpinning the UK 1974 Health and Safety at Work Act [45, 46] is that those who create risks from work activity are responsible for protecting workers and the public from the consequences, but this is not at any cost; it must reflect the values of society at large on what risks are unacceptable, tolerable or broadly acceptable. For a company operating internationally this may pose a dilemma, since social acceptance of risk might vary between, and sometimes within, countries, due to, for example, various cultural differences relating to religious or ethnic groups. This raises ethical, social, economic and scientific considerations, for example:

- whether certain hazards should be entertained at all;

- how to maximise benefits to society by taking into account advances in scientific knowledge and technology, while ensuring that undue burdens with adverse economic and social impacts, or consequences, are not imposed on the regulated;
- how to achieve the necessary trade-offs between benefits to society and ensuring that individuals are adequately protected; and
- the need to avoid the imposition of unnecessary restrictions on the freedom of the individual.

2.2.5 OH&S-MS Applicability

The OH&S-MS must apply to all relevant functions and levels within an organisation in order to achieve its common goal(s) associated with the development of its activities. In process terms, all developments, irrespective of size or complexity, tend to go through a similar lifecycle and, are generally project related since they require change and projects are considered to be the 'engines of change [48]'. It should be noted that different industries have their own terms to describe the development lifecycle phases. Table 2 shows the typical phases of a development lifecycle based on British Standard (BS) 6079-1:2010 Project management.

Table 2 Typical Development Lifecycle Phases

BS 6079-1:2002 ¹	European Process Safety Centre 1994 ²
	Inherency
Conception	Concept Selection
Feasibility	Front End Engineering Design (FEED)
Realization	Detailed Design
	Construction and Commissioning
Operations	Start-up
	Post start-up Review
Termination	Abandonment

¹ BS 6079-1:2010

² Inherency and abandonment added after 1994, re: Optimising the Lifecycle Safety, Health and Environment Impact of New Products, F. K. Crawley, Trans IChemE, Part B, November 2004

During each of these phases OH&S objectives should be set, which may not necessarily be common to each phase, or indeed the various departments or disciplines within an organisation, to ensure that the overall OH&S goal(s) of the organisation can be achieved throughout the life of the development.

“Principles and guidelines for the management of projects” [34] are as relevant to small organisations and for small projects as they are to major organisations with multimillion pound projects spanning several years, and aim to help an organisation achieve a desired outcome of a project efficiently and effectively. It also aims to contribute to the learning within projects and so continually improve an organisation’s project management capability.

In projects spanning several years, there is the potential to unwisely make sacrifices during the early phases of the project, e.g. quality, safety, cost, or schedule, which could compromise the ability of the organisation to meet its OH&S goal in subsequent phases.

2.2.6 Comparison of Management Systems

There are a number of OHS-MSs and associated quality and environmental management systems available to organisations for reference and implementation. In principle, all provide a framework based on the PDCA cycle. However, their applicability and intent varies according to the designation of the standard and its intended audience. There are three International Standards Organisation (ISO) publications covering Occupational Health and Safety (OH&S) Management Systems:

- BS OHSAS 18001: 2007 Occupational health and safety management systems. This supersedes 18001:1999 and is a management system standard for health and safety for which organisations can be audited and obtain third party certification;
- BS OHSAS 18002: 2008 Occupational health and safety management systems. Guidelines for the implementation of OHSAS 18001:2007; and

- BS 18004: 2008 Guide to achieving effective occupational health and safety performance.

This replaces BS 8800:2004 Occupational health and safety management systems guide.

18001 and 18002 are pre-fixed as British Standards (BS) Occupational Health and Safety Assessment Standards (OHSAS), whereas 18004 is a BS but without the OHSAS, since it is a guide not directly connected with certification but is intended to be used in conjunction with BS OHSAS 18001 and BS OHSAS 18002. The history of the development of the standards is relevant since it reflects the changes required by industry to help support their management system objectives. For example, BS OHSAS 18001:1999 was classified as a specification but has now been replaced by BS OHSAS 18001:2007 which is a certifiable standard. The development of BS OHSAS 18001:2007 was influenced by BS 8800:1996, which in turn was influenced by HSG 65: 1997 (which superseded HSG 65: 1991), the quality standard ISO 9001, and the environmental management system standard ISO 14001.

A key feature of BS OHSAS 18001:2007 is that it now defines a hierarchy of controls to be used, i.e. elimination, substitution, engineering controls, signage/warnings/administrative controls and, personal protective equipment. In this context it is thought to be more consistent with the principles of inherent safety, and a step ahead of HSG 65. The British Standards Institute (BSI) also has case studies that outline the problems companies were facing prior to accreditation to BS OHSAS 18001:2007, and improvements after the introduction of BS OHSAS 18001:2007. For example, the construction company AMEC saw reportable incidents reduced by 10%, while another construction company, Mansell, claimed that it led to a 16% improvement in staff productivity. Furthermore, computer company Compaq achieved a 30% reduction in employee injuries in eight months [49]. However, the history or level of safety performance, in these companies, before the introduction of the standard was not given, (e.g. it is generally easier to get significant improvements if the starting point or historical safety performance is poor) nor was any information given on whether any other drive to improve safety performance could have yielded the same, or better, results.

BSI suggests that BS OHSAS 18001: 2007 can be readily integrated with ISO 9001 and ISO 14001, and to help this integration BSI have published, PAS 99: 2006 Specification of common management system requirements, as a framework for integration [50].

The choice of which system to use depends on the needs of the organisation. For example, if an organisation already has accreditation under BS EN ISO 9001 and BS EN ISO 14001 it may consider adopting BS OHSAS 18001:2007 as part of an integrated approach [51]. However, an organisation may prefer to use a more industry-specific system such as that of the E&P Forum (now OGP) for the oil and gas industry. Currently, discussions are being held at international, European and national levels on the possible development of a single international standard (ISO standard) for occupational health and safety management systems for the oil and gas industry.

The UK HSE have carried out a comparison of the following management systems [52] against HSG 65 [32]:

- BS EN ISO 9001:2008, (Quality Management standard) [35]
- BS EN ISO 14001:2004 (Environmental Management standard) [31]
- BS OHSAS 18001:2007 (Occupational Health and Safety Management standard) [28, 44]
- ILO OSH: 2001 (Guidelines on Occupational Health and Safety Management Systems) [53]
- CIA Responsible Care Management System Framework [54]

The UK HSE summarised their findings, from this comparison, as follows:

- *“there is a high degree of similarity in their content at a high level*
- *they all reflect the common principles based on the ‘plan/do/check/act’ model of quality management, sometimes referred to as the management ‘control loop’.*

- *the route taken in all the standards, in essence, for organisations to:*
 - *identify the issues that need to be addressed,*
 - *set the direction/standards to be achieved,*
 - *plan what needs to be done,*
 - *organise who is going to do it,*
 - *equip them to carry out the activities,*
 - *do it,*
 - *check it has been done,*
 - *check that it worked; and*
 - *learn from feedback lessons from this exercise to (continually) improve (the process and outcomes)”.*

The main characteristics of the documents are:

- HSG 65 describes the systematic ‘POPMAR’ (policy, organisation, planning and implementing, measuring, auditing, reviewing) model for managing health and safety.
- BS EN ISO 9001:2000, BS EN ISO 14001:2004 and BS-OHSAS 18001:2007 are certifiable ‘standards’, the purpose of which is to help organisations create management systems and to demonstrate to their stakeholders that they have introduced management systems which have the required characteristics.
- BS EN ISO 14001:2004 is an environmental management system (EMS) standard. Environmental control standards/issues tend to be a little less complex than those associated with health and safety, which means environmental management can be more amenable to the systems approach.
- The main differences in the scope of the standards relative to HSG 65 are that there is little in the former on risk assessment, and no specific requirements for employee involvement.

- BS OHSAS 18001:2007 is a health and safety management system standard. It shows close alignment with BS EN ISO 14001:2004, quite close alignment with ILO OSH 2001, and some alignment with ANSI Z10 [55], an American National standard for health and safety management.
- ILO OSH: 2001 aligns closely with HSG 65 and the superseded standard BS 8800:2004 but has greater emphasis on employee involvement – reflecting the European emphasis on worker involvement and the tri-partite nature of its development.
- ‘Responsible Care’ is a programme sponsored by the Chemical Industries Association (CIA). It aims to promote good management of health and safety, environment and some aspects of quality in the chemical industry, for the purposes of demonstrating good performance to stakeholders. It draws on and cross-references earlier editions of the other standards outlined above.

This picture may be complicated where organisations have sought to integrate the requirements of one or more of the above (or other) standards into a single system.

2.2.7 Success factors for the implementation of an OH&S-MS

A survey by Dr Maneesh Kumar of the University of Strathclyde on the use of quality management techniques in Scottish manufacturing provides an insight into success factors, and also barriers that affect quality improvement, which could equally be translated for OH&S-MSs [56].

Given the relative commonality of management systems, the success factors, barriers and ranking are likely to be consistent for OH&S-MSs.

Table 3 lists and ranks both the success factors and potential barriers identified by in the publication “Total quality management – the critical success factors” [57].

Table 3 Quality improvement success factors and barriers

(Source: Based on an article in Total Quality Management – the critical success factors, Volume 4, Issue 1)

Success Factors		Barriers	
Factor	Ranking	Barrier	Ranking
Management support and commitment	1	Lack of management support and commitment	1
Employee involvement	2	Wrong people applying tools and techniques	8
Appropriate training	3	Lack of effective training	6
Good communication	4	Failure to communicate	2
Understanding by management of the nature of the problem	5	Lack of management understanding and acceptance	3
A conducive and cooperative workforce	6		
Employee skills and experience	7	Lack of knowledge regarding analysis and interpretation of collected data	7
Establishing the genuine need for tools and techniques	8	Employees attitude towards the use of quality improvement tools and techniques	4
		Lack of awareness and understanding on the use of quality tools and techniques	5

2.2.8 Analysis of the effectiveness of OH&S-MSs

An OGP report [27] implies that the role of an OH&S-MS in managing major accidents is unclear as these incidents are too infrequent (or random) and complex to be prevented by an OH&S-MS. However, analysis of three, post-Piper Alpha, Disaster investigation reports does not show criticism of the OH&S-MSs but their ineffective application.

It has also been argued that the current approach to safety management requires a more systemic approach as current systems place too much emphasis on management functions, guidelines and national and international standards and quality principles [58].

The UK HSE view of risk management is that it should be as low as is reasonably practicable (ALARP) through compliance with recognised Codes and Standards, hence demonstrating good, if not best, practice [59, 60]. This presupposes a more proactive and dynamic management system that enables organisations to predict change, and therefore react more effectively and efficiently, to it, similar to the Resilient Engineering approach [61]. The use of an OH&S-MS for small businesses is also criticised as it is seen as being fraught with difficulty and too bureaucratic, thereby making the application overwhelming. The UK HSE propose that small businesses must simply focus on three main control strategies: safe place, safe person and safe systems [62]. However, the criticism appears to relate to the extent of the application of an OH&S-MS, rather than the principles that underpin the OH&S-MS. Given that the OH&S-MS is simply a framework and the principles are universal, the application of the OH&S-MS and how far action is needed will depend on the size of the organisation, the hazards presented by its activities, products or services, and the adequacy of its existing arrangements. This should work for any organisation, irrespective of size and complexity. This approach is also adopted by the nuclear, rail and aviation industries since the general characteristics of an OH&S-MS and PDCA are equally relevant [63] [64] [65] [66] [67].

A further criticism of the current OHS-MS models is that they fail to adequately deal with safety during the lifecycle of a development, and therefore lack emphasis on the ability to benefit from cost-effective strategies during design when considered over the lifetime of a development. In this context the models are less specific about risk transfer between lifecycle phases and the likelihood that it will be less attractive, e.g. financially and operationally, to design out failure in later stages of the lifecycle (e.g. the operational phase) with an increased tendency to rely on lower order controls, such as procedures.

In any event, it is clear that major accidents still occur, as demonstrated by the Deepwater Horizon disaster in 2010.

The ethos that underlies an organisation's approach to safety is contained within its OH&S-MS. In the case of offshore operations, in the UK, the requirements for an OH&S-MS followed recommendations contained in the Piper Alpha Inquiry Report. This recommended, amongst other things, the requirement for a Safety Case, and that the Safety Case should confirm that the OH&S-MS of the company and that of the installation were adequate to ensure that (a) the design, and (b) the operation of the installation and its equipment, were safe [10]. There were a number of other recommendations associated with the OH&S-MS, but in particular they required that the OH&S-MS should set out the safety objectives and the system by which these objectives were to be achieved, and, that this should draw on quality assurance principles similar to those stated in BS 5750 and ISO 9000. Note that British Standard 5750 was superseded by ISO 9000 but was relevant at the time of the Piper Alpha Enquiry.

The principles associated with quality assurance and safety management are relatively aligned and this led some organisations to consider the application of total quality management (TQM), and the OH&S-MS was seen to be a subset of the TQM. It is of interest that it was suggested to the Piper Alpha Inquiry that the oil and gas industry adopt TQM to support improvements in safety. However, this was not recommended by Cullen as the implications could not be justified simply on the basis of safety [68].

It could reasonably be assumed that an international oil and gas company would apply its corporate OH&S-MS across its entire global operation, accepting any national or regional statutory limitations.

This would be ethical since it would recognise good, if not best, industry practices, thereby universally ensuring consistency and continuity in order to meet safety objectives. However, the Deepwater Horizon investigation proved that BP did not apply its corporate OH&S-MS across its global network of operating companies, and that if it had effectively applied its UK OH&S-MS, the disaster could have been prevented [6].

2.3 Margins, profits and resource allocation

2.3.1 Introduction

The following review considers certain components of OH&S-MSs. While organisations, in theory, would need to effectively implement all elements of an OH&S-MS to achieve all the benefits advocated by these systems, this research focuses on those components that are likely to have the greatest impact in meeting research objectives, but nevertheless remains indicative of the degree to which the entire OH&S-MS is being applied.

2.3.2 Economics

The economic, geographical and political environments, in which future oil and gas exploration and exploitation will be necessary, present significant challenges to companies. In addition, often, due to the complexity of old and depleted reservoirs, technical challenges can generate higher risks compared to previous operations, due to factors such as ageing, as companies attempt to maximise hydrocarbon recovery, and extend their search for new reserves of oil and gas.

The European Commission states that, *“based on frequency analysis of industry [oil and gas] performance in Europe to date and on documented costs of past accidents, the estimated average annual economic losses and damage from offshore oil and gas accidents in the Union range from €205M to €915M” [69]*

Furthermore, keeping up with demand and meeting safety and environmental regulations is becoming more difficult as existing physical infrastructure (assets) ages and breaks down. Oil and gas companies have large amounts of physical capital (refineries, offshore installations, pipelines, IT systems, etc.) that needs to be maintained and upgraded over time, representing a huge cost investment for the company, while at the same time, revenue from oil and gas production is generally declining [70]. However, despite these challenges companies still need to maintain financial margins and this has previously involved mergers and acquisitions to achieve economies of scale, etc.

For example, on 31 December 1998, BP merged with Amoco. BP Amoco's competitive planning strategy aimed to identify critical value drivers. Stonham conducted a case study that identified the approach to 'winning strategies', in the context of competition, and which lay in the discovery of value drivers and connecting these to business strategy [15]. Stonham described a Four-Quadrant Value Proposition (FQVP) that an organisation can apply to create value, i.e. shareholder value. However, compromises are normally involved in the application of the FQVP and therefore an organisation has to choose between, often, competing demands in an attempt to maximize shareholder value. In this model a dominant value driver is seen as efficiency in production with a major aim of reducing costs. Consequently, as a company has no direct influence on oil price, it can only influence margins, and these depend on costs and throughput volume.

According to the FQVP, major oil companies are placed in the model where competition is intense, and new markets, geographically, are continually being sought and the allocation of resources adjusted accordingly. Speed in reaction to changing market conditions is also important, especially given the volatility of oil prices and the need to maximise margins. However, rapid change can also have a negative impact. For example, in 1990 BP appointed Robert Horton as chairman and Chief Executive Officer (CEO). While he inherited strategic inconsistency his subsequent policies of restructuring and reorganisation were too rapid, and the implementation too confused. Consequently there were significant job losses, and BP's profits fell 20 percent against the oil sector and 33 percent against the London Stock Market. Horton was dismissed in 1992 and the new chairman and CEO changed the strategy. From 1992 onwards, BP concentrated on cutting costs so that it could return a margin even at the lower end of volatile oil price cycles.

BP also introduced a concept of 'gain-sharing' an alliance with contractors to drive development and reduce operating costs. Costs were also attacked in employment. The peak year for layoffs in this period was 1992 when 14,500 jobs were cut. Between 1993 and 1995, a further 9000 jobs

were eliminated, and a target of 5000 more out of a total of 56,650 employees worldwide was set in 1995.

Early in 2000 the price of Brent Crude oil peaked at \$32 a barrel, virtually tripling the 1998 price. This allowed BP to introduce the strategy of 'rebalancing' cost reductions with growth [15, 71]. However, it is argued, in the BP Texas City [2005] and Deepwater Horizon investigation reports, that this culture of cost-cutting became so entrenched and endemic in BP that eventually it contributed to both the Texas City and Deepwater Horizon disasters as discussed later in this thesis [6, 18].

The Economist Research Unit has published a report, 'The Long View: getting new perspective on strategic risk', that suggests a short term focus on profits is downgrading the agenda given to risk and opportunity in the boardroom [72]. It is expected that the competitive and financial strategy used by BP Amoco, during this period, will have been consistent with the approach taken by other companies operating in the private sector of the oil and gas industry. This assumption is considered valid, given the intense competition between companies and their inability to independently influence the oil price. Consequently, in the case of the oil and gas industry, where private companies cannot dictate oil price, optimising margins by minimising costs and maximising production, and therefore revenue, is a necessity, especially given the often unpredictable and cyclical nature of the oil price.

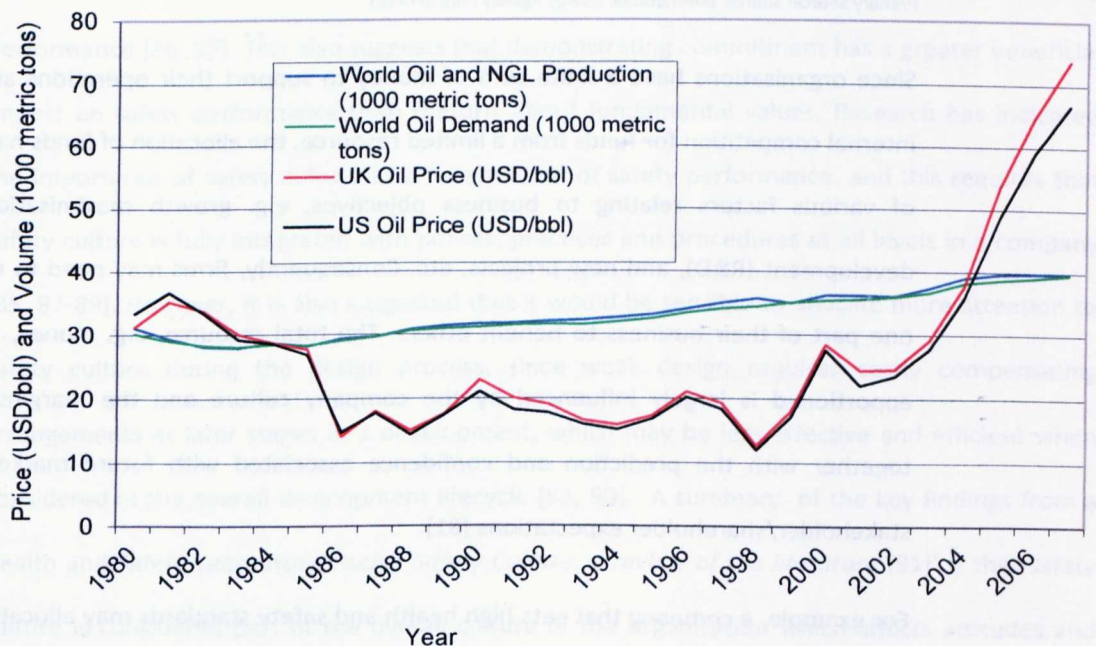
In these circumstances it is also realistic to consider that the cost centre, or overhead, associated with safety management, may be compromised since it does not generate revenue and tends to increase operating costs. The margins that organisations can achieve, and in turn their profitability, largely determines the allocation of resources available to satisfy business objectives. However, margins and profitability are also inextricably linked to the perpetual conflicts between the oil and gas companies and the nations that control the reserves, the variability of supply and demand, the politics of national and international energy strategy, including the arguments over

climate change and renewables, the influence of the oil and gas traders, and the personal ambitions of the chief executives who manage those organisations [73].

Oil and gas companies also operate in a mode of constant change. For example, not only are there uncertainties about future oil and gas prices but organisations are perpetually changing, not only through acquisitions and mergers, but also as people are recruited, leave, or move internally through a company.

Oil and gas prices have been extremely volatile [74-77] (Figure 11 and Figure 12), using crude oil as an example. Figure 11 shows a relatively steady increase in production and consumption of oil-based products while prices show much greater volatility. Variations between supply (production) and demand (consumption) are often due to rounding of data, the classification of materials, and stock changes over time [78].

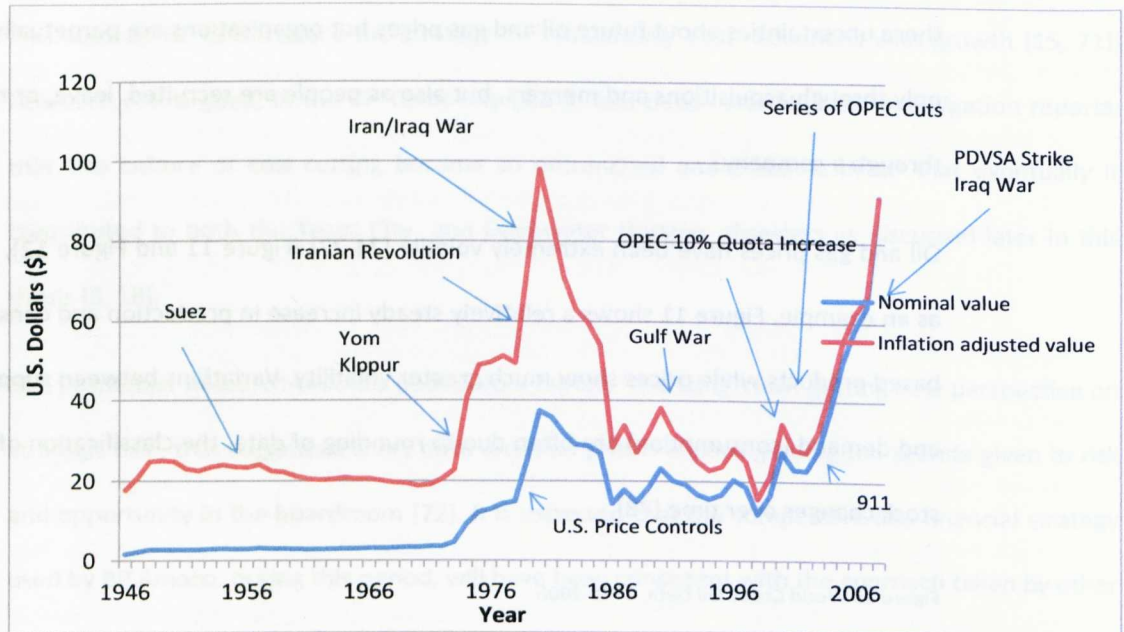
Figure 11 World Crude Oil Data, 1980-2006



Source: ESDS International, Crude Oil Import Costs (USD/bbl) and Index (Nat. Cur.), 1980 - 2008, ESDS International, (Mimas) University of Manchester.

The oil price (Figure 12) shows a much more variable performance, partly due to some of the crises illustrated on the chart [79, 80].

Figure 12 Oil Prices 1946 – 2008



Primary Source: Source: International Energy Agency Data Services

Since organisations have a finite sum of money to support their operations and there is often internal competition for funds from a limited resource, the allocation of funds has to take account of various factors relating to business objectives, e.g. growth maximisation, research and development (R&D), and new projects, etc. Consequently, firms may need to make sacrifices in one part of their business to benefit others. The total resource, e.g. money, and the way it is apportioned is largely influenced by the company culture and the margins it has achieved together with the prediction and confidence associated with future market conditions and stakeholder/shareholder expectations [81].

For example, a company that sets high health and safety standards may allocate, as a proportion of a finite sum of money, more funds to seek improvements in safety than a comparable company that might be relatively indifferent to safety performance. However, this may change year-on-year, depending on company dynamics and its safety culture.

2.3.3 Safety Culture

The relatively recent introduction of the term 'Safety Culture', often used interchangeably with 'safety climate' reflects, in part, the move within the industry, from technological solutions to improvements in safety performance, to more psychological and behavioural strategies [82].

However, there is no universal agreement or definition on what constitutes safety culture, but it tends to include concepts such as shared norms, values, attitudes, perceptions and behaviour, with assumed relevance for safety [81-85].

It is recognised that major oil and gas companies operate on a global basis and therefore have to deal with many cultural differences in everyday business. It is therefore argued that while organisational safety culture may be a universal value, its importance, in terms of organisational attributes and practices, may vary across national and regional cultures [86].

It is suggested that perceived management commitment and support reflecting employee care in the organisation will lead to more positive safety behaviours and, in turn, improvement in safety performance [86, 87]. This also suggests that demonstrating commitment has a greater beneficial impact on safety performance than rhetoric about fundamental values. Research has indicated the importance of safety culture as a determinant of safety performance, and this requires that safety culture is fully integrated with policies, practices and procedures at all levels in a company [85, 87-89]. However, it is also suggested that it would be sensible to allocate more attention to safety culture during the design process, since weak design requires costly compensating arrangements at later stages in a development, which may be less effective and efficient when considered in the overall development lifecycle [82, 90]. A summary of the key findings from a Health and Safety Laboratory study, '*Safety Culture: a review of the literature* [91]' is that safety culture is considered part of the overall culture of the organisation which affects attitudes and beliefs, such as health and safety performance, and that management had a key influence on an

organisation's safety culture. However, different levels of management could influence safety culture in different ways.

While much of the literature relating to safety culture explores its esoteric elements, variations and implications in relation to safety performance, it often fails to develop the connection between safety culture and resource allocation that permits organisations to adequately fund the application of their OH&S-MS, and therefore to achieve safety performance objectives. For example, many oil and gas companies have targets of zero injuries. Furthermore, a manager may wish to increase expenditure to improve safety performance but may be limited by the funds available.

The impact of poor risk management is likely to adversely affect an organisation's management, staff, shareholders, customers and other stakeholders. In BS 33110 it is stated that, *"risk management has to continuously, systematically and proportionally address the risks surrounding an organisation's activities. It cannot be separated from the culture of the organisation [92]"*. Risk management, an intrinsic component of an OH&S-MS, also comprises a framework and process that enables an organisation to manage uncertainty in an effective, efficient and systematic way from strategic, programme, project, and operational perspectives, as well as supporting continual improvement. Risk management applies at all levels of an organisation and to all activities.

In an article, *"Improvements are badly needed offshore"*, it was stated by Ian Whewell of the UK HSE, at the North Sea Offshore Authorities Forum (NSOAF) that, *"The key to embedding a successful health and safety culture is strong and active leadership from the top. Those who create risks are best placed to manage them...but we should not underestimate the range of challenges the industry faces"* [93]. In this context, one challenge relating to safety culture is about retaining 'corporate memory' and continuous enforcement of safety good/best practices to avoid complacency or forgetfulness.

This was reinforced by Magne Ognedal, Director-General of Norway's Petroleum Safety Authority (PSA) who said, *"The hard learned lessons from catastrophic incidents like the Alexander Kielland capsizing and the Piper Alpha explosion and fire seem to be getting forgotten by the industry [94]"*. The Deputy Director-General of the Danish Energy Agency, Anne Højer Simonsen, added that process safety improvements are badly needed and that it is essential that lessons are known and understood. She continued, *"to be a zero-incident industry we need to learn from best practices not only in the offshore industry but also from other industries in the North Sea countries and other parts of the world. Best practices can be gauged by using the right key performance indicators (KPIs). It is, therefore, essential that we focus on further development of KPIs in the offshore sector"*.

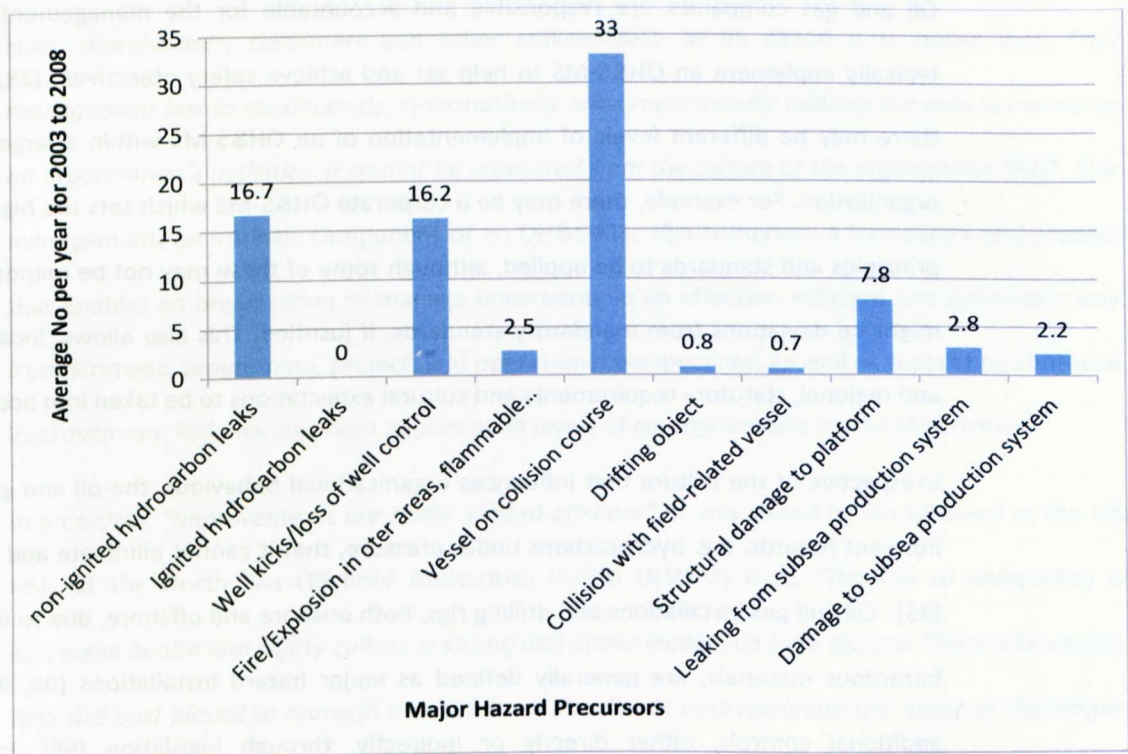
Oil and gas companies are responsible and accountable for the management of safety and typically implement an OH&S-MS to help set and achieve safety objectives [28, 32]. However, there may be different levels of implementation of an OH&S-MS within a large multi-national organisation. For example, there may be a corporate OH&S-MS which sets the high level policies, principles and standards to be applied, although some of these may not be mandatory and there might be deviations from mandatory standards, if justified. This also allows 'local', e.g. national and regional, statutory requirements and cultural expectations to be taken into account.

Irrespective of the culture that influences organisational behaviour, the oil and gas industry has inherent hazards, e.g. hydrocarbons under pressure, that it cannot eliminate and has to manage [95]. Oil and gas installations and drilling rigs, both onshore and offshore, due to the inventory of hazardous materials, are generally defined as major hazard installations [96, 97] that invoke additional controls, either directly or indirectly, through legislation [65]. In these cases, organisations responsible for major hazards are required to implement controls to reduce both the likelihood and consequences (risk) of a failure and, depending on the regulatory regime or company policy, to reduce residual risk to a level that is as low as reasonably practicable (ALARP) [17].

In the Norwegian petroleum industry attempts have been made to identify relationships between different data sources and the root cause of major accidents, Figure 13 and Figure 14, but these have been inconclusive, although a study carried out in 2007, while not identifying any correlation between leaks and safety climate, did identify a significant correlation between the number of leaks and activity levels, but this relationship is not recognised in current quantitative risk analysis (QRA) models [98].

However, a more recent study appears to have identified a correlation between leaks and safety climate, because the data collection, which includes major accident precursor data and biannual questionnaire survey data, is seen to be more extensive than in previous studies [99].

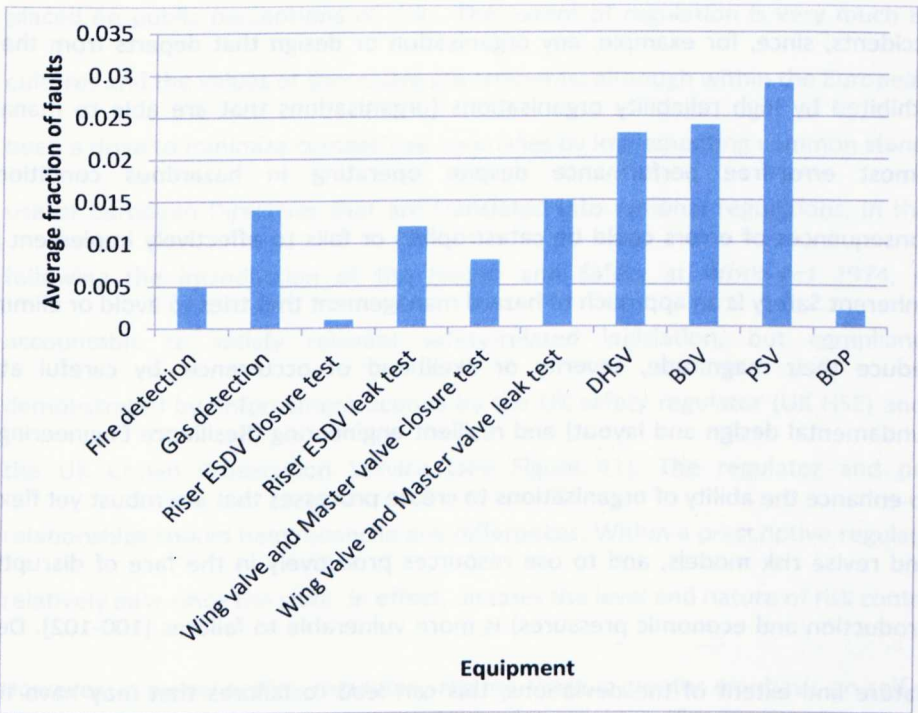
Figure 13 Overview of major hazard precursor categories



The survey did not identify any correlation between barrier performance and leak frequency. Figure 13 shows that there were, on average, 32.9 incidents involving non-ignited hydrocarbon leaks, well kicks, and loss of well control, between 2003 and 2008. These incidents are directly

influenced by the platform management systems, whereas incidents relating to vessels on a collision course with the installation are generally outside the scope of the Operator's OH&S-MS.

Figure 14 Relative numbers of faults for selected barrier elements, 2008



In the study, variations in the number of potential leak paths were taken into account since larger installations are assumed to have a higher leak frequency.

The survey data analysed was limited to personnel that could influence the likelihood of hydrocarbon leaks, i.e. process operators and maintenance personnel. It was shown that virtually all the correlation and linear regression results were significant in relation to leak frequency.

Figure 14 shows the relative number of faults for selected barrier elements. It is evident that many of the important safety critical components, i.e. those components where failure can result in a major accident, such as the DHSV, BDV and PSV, have relatively high failure rates.

J.E. Vinnem, argues that personnel tend to focus their response based on a relatively high number of injurious incidents and therefore it is much more difficult to identify correlations between

safety climate and major hazard precursors that tend to be process-related, particularly given the large number of influencing variables [98].

This research provides some clues to this relationship, i.e. between safety culture and major accidents, since, for example, any organisation or design that departs from the characteristics exhibited by high reliability organisations (organisations that are able to manage and sustain almost error-free performance despite operating in hazardous conditions where the consequences of errors could be catastrophic) or fails to effectively implement inherent safety (Inherent Safety is an approach to hazard management that tries to avoid or eliminate hazards, or reduce their magnitude, severity or likelihood of occurrence, by careful attention to the fundamental design and layout) and resilient engineering (Resilience Engineering looks for ways to enhance the ability of organisations to create processes that are robust yet flexible, to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures) is more vulnerable to failures [100-102]. Depending on the nature and extent of the deviations, this can lead to failures that may have the potential for escalation to major accidents.

2.4 Regulation and the role of the regulator

2.4.1 Background

Exploding steam boilers emerged as a public hazard, in the United States of America (USA) in the mid-19th century, to the extent that, in 1836, 496 lives were lost in 14 explosions, which resulted in Congress passing a law requiring boiler inspectors and imposing severe fines and prison terms if owners and employees were negligent [103]. The problem was not so significant in the United Kingdom and similar laws were not passed until 1852. These illustrate state intervention in private enterprise as employees could not necessarily rely on employers to protect them from specific hazards and therefore government intervention was required through regulation to control some industrial risks.

However, since the 19th Century and, with the rapidity of technological development, e.g. the industrial revolution, and its associated hazards, the public has increasingly influenced the type and extent of safety regulation, with less emphasis on scientific argument and more credence placed on public perceptions of risk. The extent of regulation is very much based on national cultures and the values of successive governments; although within the European Union there has been a drive to minimize competitive anomalies by implementing common standards through the use of European Directives that are translated into national regulations. In the UK, particularly following the introduction of the Health and Safety at Work Act 1974, organisations are accountable to satisfy relevant safety-related legislation, but compliance is varied as demonstrated by enforcement actions by the UK safety regulator (UK HSE) and prosecutions by the UK Crown Prosecution Service (see Figure 41). The regulator and public-organisation relationships should help reconcile any differences. Within a prescriptive regulatory regime this is relatively easy since the state, in effect, dictates the level and nature of risk control.

However, in a goal-setting regulatory regime there is greater emphasis on self-regulation, which makes proactive regulatory intervention more difficult, since the degree to which risks are controlled is more reliant on those that create them, and therefore the regulator generally only intervenes if things go wrong. However, despite decades of offshore activity, and prescriptive, and goal-setting safety legislation the European Commission is proposing new regulations [69] which are justified on the basis that, *"the risk of a major offshore oil or gas accident occurring in Union waters is significant and the existing fragmented legislation, and diverse regulatory, and industry practices do not provide for achievable reductions in the risks throughout the Union"*. Much of the proposed regulation is based on the existing UK offshore Safety Case regime and EU onshore COMAH Regulations. However, the proposals extend current regulatory regimes by adding key safety objectives to ensure consistent use of best practice for major hazards by all offshore oil and gas operations in Union waters, and to implement best regulatory practices.

Furthermore, there are variations in international regulatory safety regimes although most oil and gas companies operate globally. For major hazards, a report for the Commission for Energy Regulation (CER), the independent body responsible for Ireland's electricity and gas sectors, *"Review and Comparison of Petroleum Safety Regulatory Regimes for the Commission for Energy [onshore and offshore] Regulation"*, compared regulation in the UK, Denmark, Norway, Australia (Western) and Canada (Nova Scotia) [104]. The report concluded that while all have risk-based approaches and a permissioning regime (e.g. a safety case regime where the regulator has to accept and approve a case for safety before allowing a relevant operation), there are also three key differences. These are the inclusion of occupational hazards in their major hazards legislation, except the UK, the use of third parties for compliance assurance activities, where only the UK extends this to include operations, and the level of detail in the legislation where there is a wide range of differences in the guidance provided to accompany the legislation.

2.4.2 The UK Regulator

The role of the UK regulator is largely subject to government influence and the economic conditions, since these affect the level of public expenditure and in turn public sector staffing. The level of regulator involvement, and enforcement, is reflected in their available resources. Often, in times of recession, public expenditure is cut and so are staff numbers [105, 106]. Safety may be compromised, either by lack of inspection, as evidenced by the Piper Alpha, BP Texas City and Deepwater Horizon investigation reports, or, the inability to obtain advice and support from either the regulator or company safety professionals [107]. It is noted that as a result of the Piper Alpha Enquiry responsibility for offshore safety was transferred from the Petroleum Engineering Directorate (part of the then Department of Energy) to the UK HSE, since it was not considered independent and well-fitted to carry out the functions of a regulatory body with regard to safety. This is a recurring theme, as it was similar to the situations regarding BP Texas City and Deepwater Horizon.

To support the regulatory process, risk analysis is significant in policy making since it produces a systematic approach to evaluate risks, particularly at the macro-level, by typically bringing together various bodies representing the issue being assessed. There are four generic approaches to risk analysis:

- The original engineering approach geared towards the quantification of risks;
- Decision analysis that takes account of other contributory factors, such as environmental and economic issues;
- Risk-perception studies that seek to understand why people have different values, and therefore priorities, that might be contrary to those based on scientific evidence; and
- Policy-analysis methods that try to explain how social and political influences affect risk policies [108].

Following the Deepwater Horizon disaster, a hearing was held by the UK House of Commons Energy and Climate Change Committee, to look into the implications of the disaster. The committee were told by Malcolm Webb, Chief Executive of Oil and Gas UK, representing the North Sea oil and gas industry, and Paul King, Managing Director of Transocean Drilling UK, that the UK regulations are 'superior' to the approaches of other nations, and they argued against a pan-European regulatory body [109]. This implies that companies operating globally do not necessarily apply common standards and practices across their operation, and reinforces the assertion that the UK provides a safety benchmark of good, if not best, practice. However, since Oil and Gas UK represent the UK oil and gas industry and the U.S. parent company of Transocean Drilling UK were subject to litigation in the United States as a result of the Deepwater Horizon disaster, it is unlikely that either would suggest otherwise. The UK HSE discharge their responsibilities by applying a Compliance Code which is a statutory Code of Practice to encourage regulators to meet their objectives in a way that minimises the burdens on business [110]. The Code encompasses a risk-based, proportionate, targeted, and flexible approach to regulatory

inspection and enforcement, to ensure effective and efficient use of resources, and since the early 1990s, the UK HSE has followed the Code's five principles of good regulation, that are:

- *"proportionality,*
- *accountability,*
- *consistency,*
- *transparency, and*
- *targeting"*.

The Code applies when regulators determine their general policies or principles about how they exercise their regulatory functions but does not apply them to individual enforcement decisions. The Code is also based on the seven principles of inspection and enforcement set out in the report *"Reducing administrative burdens: effective inspection and enforcement" [111]*". In summary key requirements are that regulators only intervene when there is a clear case for protection (therefore not without reason) and avoid unnecessary disruption to economic progress. They should prosecute habitual offenders but proactively provide cheap and readily accessible advice, and be accountable for the conduct of their activities.

These principles are not wholly consistent with good practice in that they reflect reactive rather than proactive safety management.

2.4.3 The U.S. Regulator

The U.S. equivalent to the UK HSE is the Occupational Safety and Health Administration (OSHA) [112], whose mission is to prevent work-related injuries, illnesses, and deaths. OSHA presently (2012) has a staff of 2,200 inspectors, 10 regional offices, and 90 local area offices. In 2011 their budget was \$573,096,000 and they inspected 40,215 workplaces. OSHA state that reports of imminent accidents are their top priority, second are fatalities or accidents serious enough to send three or more employees to the hospital, and third are employee complaints. Referrals from other government agencies are fourth, and fifth are targeted inspections such as through the '*Site Specific Targeting Programme*', which focuses on employers that report high injury and illness

rates, and special emphasis programmes that zero in on hazardous work. Follow-up inspections are the lowest priority. Typical OSHA programmes include an Alliance Programme designed to involve employers, labour unions and trade/professional groups in the prevention of accidents and illnesses in the work place, and a Voluntary Protection Programme (VPP) that recognises exemplary safety programmes to use as a demonstration of best practice for other industries and communities.

Under the U.S. Occupational Safety and Health Act of 1970, OSHA's role is to ensure safe and healthful working conditions for working men and women, by: authorising enforcement of the standards developed under the Act; assisting and encouraging the States in their efforts to assure safe and healthful working conditions, and providing for research, information, education, and training in the field of occupational safety and health.

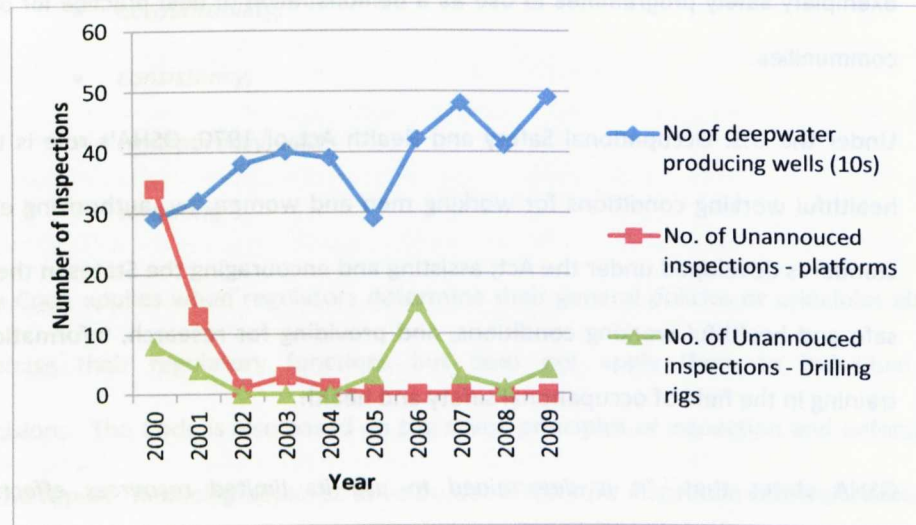
OSHA states that, *"it is determined to use its limited resources effectively to stimulate management commitment and employee participation in comprehensive workplace safety and health programs," and "because workplace inspections are one of OSHA's principal activities and because voluntary efforts to improve working conditions ultimately depend on strong enforcement, our surveys focus primarily on the inspection process"*.

Following the Deepwater Horizon disaster, the then United States Minerals Management Service, came under fire for what its critics described as lax oversight of the oil industry [113]. Examples given were:

- no surprise inspections of any of the 50+ deepwater offshore installations were carried out, despite the number of deepwater wells increasing (from 256 to 602 in a decade) and a law requiring periodic unannounced inspections, and therefore safety violations may have been present but not adequately managed, Figure 15;
- inspectors spent 62 hours onboard the Deepwater Horizon in 2009, and the same again three weeks before the disaster in 2010, both of which were announced inspections, but no citation was issued. Congress is considering drafting a bill in the wake of a deadly

mining disaster in West Virginia, to make it punishable by five years in prison to tip off an operator about an unannounced inspection [114] ;

Figure 15 GoM Regulatory Inspections 2000 – 2009
(Source The Wall Street Journal, October 12, 2010)



- the government and inspectors have been faulted by internal investigators for being too close to oil companies; and
- Donald Howard, a former MMS regional supervisor, required inspectors to give 24-hour notice before inspecting many of the largest installations because of new security regulations following the 9/11 attack. However, the U.S. Coastguard, which oversees security rules, said it could not justify this requirement.

The Interior Secretary Kenneth Salazar also promised extensive changes and named a new Director with a broad mandate covering overall policies and enforcement practices. Some of these issues have a certain parallel with the outcome and recommendations of the Piper Alpha Enquiry, e.g. the transfer of safety responsibilities from the Department of Energy to the Health and Safety Executive.

2.4.4 Enforcement

Pre-Piper Alpha, safety regimes were, traditionally, prescriptive [115-123] and therefore the role of the regulator was to ensure compliance with relevant legislation. However, unlike the penalties given to drivers who exceed speed limits, the initial approach taken by regulators was to negotiate with employers to seek compliance on the basis that if the organisation had ownership of the problem, compliance would be more sustainable. Depending on the nature of the risk, organisations would be given time to remedy non-compliances, and only when there was a continued failure to act appropriately would the regulator resort to prosecution.

Typically in this scenario, the regulator is more liable to prosecute following an incident, although it is believed that the prosecution is often retributive, i.e. aimed at satisfying public demand, rather than deterring further offences [124].

In the U.S., following the enactment of the Federal OHS Act in 1970, a policy was adopted of penalising all regulatory violations discovered by inspectors. There is good evidence that this policy was successful in reducing accident rates [125]. The penalties were essentially on-the-spot fines. There is also general agreement that prescriptive regimes which rely primarily on persuasion have been relatively ineffective in securing compliance with regulatory requirements. Another reason which has been identified, as to why prescriptive safety regimes have been ineffective, as evidenced in the Piper Alpha Inquiry, is that prescriptive legislation lags behind the development and introduction of new technologies and techniques, and therefore, in some instances, becomes irrelevant as a means of securing adequate health and safety performance.

In the UK, the above factors led a move away from the prescriptive approach, to a goal-setting regime, although various prescriptive legislation still exists [126-130]. This is an idea that has been taken from common law and turned into a regulatory requirement.

Therefore, the owner or duty holder remains, in principle, free to decide just how to comply, although compliance with good practice, e.g. codes of practice and standards, is seen to be a means of demonstrating this requirement [131]. In the UK Offshore Installations (Safety Case) Regulations 2005 this means the operator in the case of a production installation. Unlike prescriptive legislation, it is much harder for the regulator to establish whether an organisation has achieved its duty of care, and therefore a suitable level of compliance within the goal-setting regime. However, the move from prescriptive to goal-setting is likely to be adopted in the U.S. For example, in a recent article in the UK publication *"Health and Safety at Work"* it is stated; *"The Deepwater Horizon disaster seems to have convinced the US to drop its largely prescriptive approach to offshore safety as investigations into disasters such as Alexander Kielland, Ocean Ranger and Piper Alpha criticized over-reliance on prescriptive regulation, with an inspection model that is fundamentally reactive and incapable of driving continuous improvement. A similar charge is now levelled at the regulator overseeing the companies involved in Deepwater Horizon"* [132].

Whether the role of the regulator is effective and meets aspirations, as described above, may be in doubt. For example, in the BP Texas City (2005) investigation by the U.S. Chemical Safety and Hazard Investigation Board, it is stated that; *"OSHA enforcement at the BP Texas City refinery was also examined. In the years prior to the incident, OSHA conducted several inspections, primarily in response to fatalities at the refinery, but did not identify the likelihood of a catastrophic incident, nor did OSHA prioritize planned inspections of the refinery to enforce process safety regulations, despite warning signs. After this incident, OSHA uncovered 301 egregious, willful violations for which BP paid a \$21 million fine, the largest ever issued by OSHA in its 35-year history. Prior to OSHA issuing citations, the refinery had two additional serious incidents. Despite the large number of major violations on the Isomerization unit (ISOM) unit, and these two additional serious incidents in 2005, OSHA did not conduct a comprehensive inspection of any of the other 29 process units at the Texas City refinery. OSHA's national focus on inspecting facilities with high personnel*

injury rates, while important, has resulted in reduced attention to preventing less frequent, but catastrophic, process safety incidents such as the one at Texas City. OSHA's capability to inspect highly hazardous facilities and to enforce process safety regulations is insufficient; very few comprehensive process safety inspections were conducted prior to the ISOM incident, and only a limited number of OSHA inspectors have the specialized training and experience needed to perform these complex examinations". While it is accepted that regulator inspections do not guarantee the identification of all potential safety violations, it is also acknowledged that an inspection regime of zero or limited inspections is unlikely to incentivise the industry to manage safety appropriately.

An article in, *"Health and Safety at Work"* (September 2010) quotes a report entitled *"Regulatory Surrender: Death, Injury and the Non-Enforcement of Law"*, published by the UK Institute of Employment Rights. Based on a study by researchers at the University of Liverpool and Liverpool John Moores University [133] it states that since 1997:

- *"Deregulation by the Labour government's business friendly agenda has damaged its ability to enforce health and safety legislation, therefore there has been a collapse in HSE inspection, investigation and enforcement activities in pursuit of better regulation;*
- *Across the whole period 1997/1998 to 2008/2009 HSE prosecutions fell by almost a third, although statistics for the 10 years 1999/2000 to 2008/2009 show there was a drop of 48%;*
- *Since 1997/1998 there has been a 29% decline in Prohibition Notices, but a small rise of 10% in the number of Improvement Notices;*
- *HSE inspectors now only conduct a third of the inspections they did 10 years ago;*
- *Most serious injuries are now not investigated;*

- *There has been a 63% fall in investigations following mandatory reporting of injuries in the period 1999/2000 to 2008/2009; and*
- *The HSE does continue to investigate 100% of fatalities”.*

On 1 October 2008, Part 3 of the UK Regulatory Enforcement Sanctions Act 2008 came into force. The Act aims to make regulations easier to administer by allowing regulators to impose civil penalties instead of prosecuting in the criminal courts.

The UK HSE is thereby empowered to use the following penalties:

- *“Fixed monetary penalties, intended to penalise minor non-compliances;*
- *Discretionary requirements (paying a viable monetary penalty, the amount being decided by the UK HSE to help prevent repeat offences); and*
- *Stop Notices, similar to Enforcement Notices (Improvement or Prohibition), which stop recipients from carrying on with the activity specified in the Notice” [134].*

Appeals are available for any of the above penalties.

They can also accept voluntary enforcement and undertakings, i.e. giving the offender the opportunity to make an offer to take steps to correct its behaviour, and make amends for any effects that behaviour has already had.

2.5 Project and Risk Management (Including Safety in Design)

2.5.1 Project Management

The design of process plants, particularly large complex plants, processing hazardous substances, is carried out over a period of time, and involves a large number of different disciplines and discrete development phases. When considered over the lifetime of a development, the decisions made during the early stages of design can have a profound impact on the subsequent performance of a facility. From a safety perspective, the aim should be to eliminate hazards rather than devise methods to control them [135]. The greatest opportunities to reduce risks, in terms of cost-

effectiveness when considered over the lifecycle of a development, are during the early design phases. Once into detailed design there may be limited scope to apply hazard avoidance (as opposed to prevention) methods since the costs are likely to escalate and the implemented safety measures will be less effective than inherent safety measures, as passive controls will be substituted by active controls, and operating procedures [95].

Project management is, by definition, management of any activity that introduces a new objective or causes change, and has a definite start and finish time. BS 6079-1:2002, Project Management, Part 1 Guide to project management [34], states;

“The application of sophisticated project management techniques to projects in government and industry has become necessary to ensure the achievement of business, economic, environmental, strategic and political goals”.

Notably here no specific mention is made of safety. The benefits of good project management are not restricted to large projects since project management principles are not necessarily size related, and all projects follow a similar sequence, such as:

- Conceptual (this addresses questions such as: is the project technically realistic? is it commercially and financially acceptable? is it sufficiently profitable?);
- Feasibility (this evaluates all potential options and involves the selection of the optimum solution). Optimum generally means in the context of an evaluation of technical, financial and HSE issues
- Implementation (this covers design, construction and commissioning of the selected option);
- operation; and
- abandonment

However, the precise description and therefore activities associated with each stage or phase can vary. For example, the project phases, defined in BS 62198 Project Risk Management [136], are

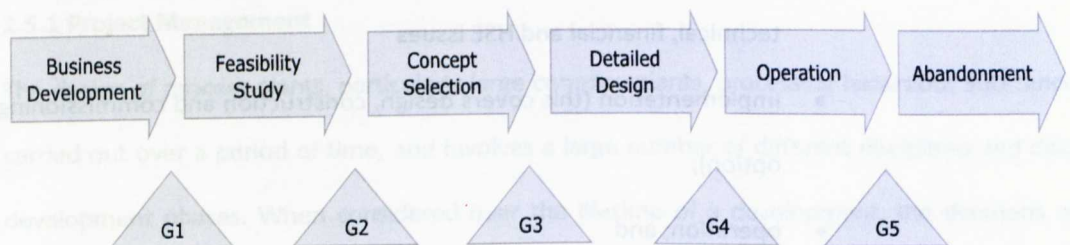
given different headings to those in BS 6079 Project Management. BS 31100:2008, Risk Management Code of Practice states that effective risk management can help an organisation achieve its goals by, for example, reducing the likelihood of adverse events and increasing the likelihood of positive events, identifying where taking risks may be beneficial, improving accountability, transparency and decision-making, managing change in complex organisations, ensuring statutory compliance, improving margins and profitability, and protecting reputation and enhancing [92].

However, this standard does not make any specific, or explicit, link to the risk management tools and techniques to be employed at each phase of the project lifecycle, and associated deliverables in subsequent phases. Consequently the literature that includes references to project management tends to treat lifecycle phases in relative isolation, although not exclusively [34, 136, 137].

Before a project is allowed to continue from one phase to the next, an independent team typically makes a formal decision, normally based on various screening criteria relating to technical, commercial, financial, and HSE performance, whether the project remains viable to continue.

One description, based on the work by Urban Kjellén [138], illustrated in Figure 16, uses Decision Gates set at strategic points in the development lifecycle

Figure 16 Development lifecycle with decision gates



BS EN ISO 20815:2008 [139] provides a further insight into project phases but has recommendations on which processes should be performed as a function of the project. The standard also provides recommendations on when the processes should be applied (in what life-

cycle phase). However, this is relatively high level, and does not prescribe the specific safety studies and deliverables that are needed during each phase. The categorisation of risk (in BS EN ISO 20815:2008) depends on factors relating to:

- The maturity of the technology;
- Whether operations are within or on the boundaries of the operating envelope; and
- The scale and complexity of the project;

While the literature presents variation in definitions, lifecycle phase classifications and descriptions, there are nevertheless several key common features of projects, such as [48]:

- *“they are non-repetitive and tend to have significant unique features likely to be novel to the management;*
- *they carry risk and uncertainty; and*
- *they are usually in the hands of a temporary team, and may be subject to change as the work progresses”.*

Given the nature of projects, particularly large ones, organisations rarely recruit employees for the entire team since they are typically of relatively short duration. Also, there may not be a continuation of projects and different projects may require different skills sets. Consequently projects are predominantly staffed by temporary or agency employees, i.e. contractors, but often with company personnel in key roles, such as the Project Manager. Once a project is completed, the team will often disband. While this offers certain advantages to an organisation, there are also many disadvantages.

For example, project teams generally have no ownership of a project covering its entire lifecycle.

This can mean that:

- Risks can be easily transferred, as the project team will no longer exist in subsequent lifecycle phases to take accountability for their design;

- Temporary contracting staff may not have the experience and expertise in relation to an Organisation's existing policies, procedures and practices to ensure adequate application of relevant 'internal' standards, and suitable levels of consistency between designs and operating systems;
- Project teams, given their temporary nature, and due to the relatively high costs of many projects, normally have relatively rigid cost and schedule targets; and
- Project teams are often incentivised to meet cost and schedule targets.

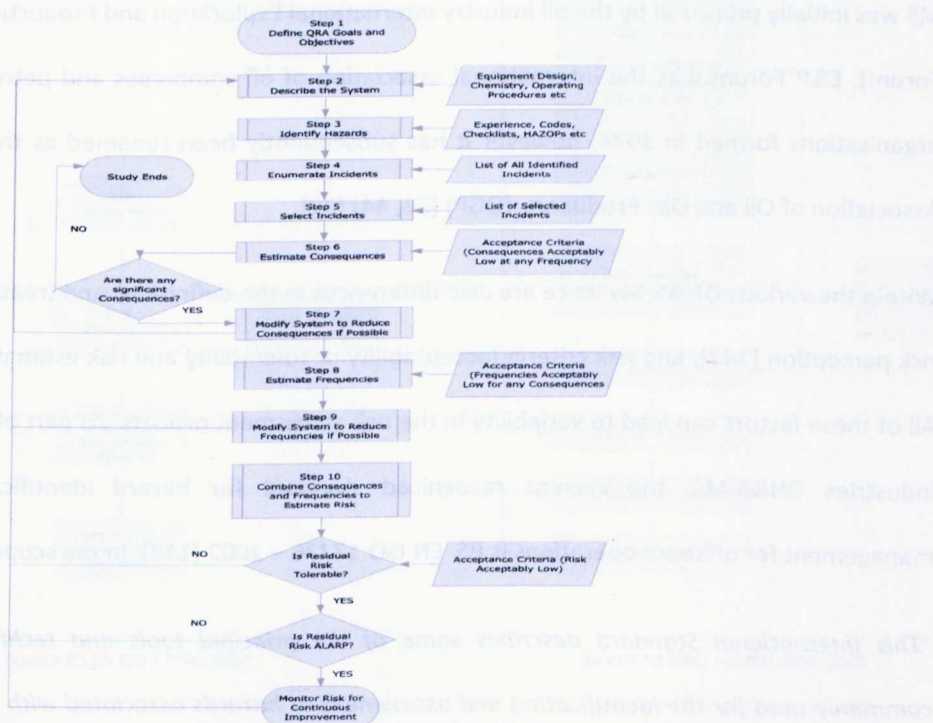
Furthermore, project teams may have a tendency to be optimistic about project costs and schedules to satisfy initial business screening criteria and therefore ensure project viability. If overly optimistic project plans are proposed, then, during the initial project phases, the resources required to deliver the project can be adversely squeezed. This has the potential to sacrifice quality and safety, and to increase the level of risk transfer to subsequent phases to avoid compromising Capital Expenditure (CAPEX) cost and schedule. The literature that examines this effect is limited and further work is essential to understand, for example, how risk transfer decisions are understood and made by project teams, and how these risks are accommodated in subsequent lifecycle phases. It is argued that the way costs are allocated during the entire development lifecycle may not encourage features of safety management, such as inherent safety in design. For example, initial project cost, i.e. CAPEX, is typically ring-fenced to ensure project viability and to meet project financial targets.

To reduce or maintain CAPEX, risks might be transferred to the operating or abandonment phases where risk mitigation often has to be achieved through lower order controls to preserve Operating Expenditure (OPEX), especially as the implications of higher OPEX is to put more strain on budgets as oil and gas reservoirs decline and the unit costs of production rise. Safety improvement in the operational phase then becomes progressively more difficult, technically, operationally and financially.

2.5.2 Safety (Risk) Management – General Principles

The OH&S-MS applies to all project development phases; therefore risk assessment is an intrinsic component of each phase. 'Risk management' is the term generally used to cover the whole process of identifying and evaluating risks, and establishing whether the controls in place, or to be put in place, provide 'acceptable' residual risks to people, the environment, assets or reputation. Other terms used synonymously are hazard management [140] and risk assessment (the term hazard and risk, together with other relevant terms, are also defined in the Glossary). While risk management can be applied in numerous types of government and private sector organisations, in this research it is related to the risks from technological systems, such as the physical processes associated with oil and gas exploration and exploitation. There are two primary types of risk assessment: qualitative or quantitative. The risk assessment process is illustrated in Figure 17 and is based on a diagram in "Guidelines for Chemical Process Quantitative Risk Analysis" [141].

Figure 17 Illustration of a risk assessment process used in the oil and gas industry



As with many topics relating to occupational health and safety, there are variations in the definitions of the terms used. For example:

- risk is the threat that an event or action will adversely affect an Organisation's ability to maximise stakeholder value and achieve its business objectives and business strategies;
- risk arises as much from missed opportunities as it does from possible threats [142];
- risk is a combination of uncertainty and damage [141]; and
- risk is a combination of the likelihood of the occurrence of a hazardous event or exposure(s), and the severity of injury or ill health that can be caused by the event or exposure(s) [28].

In general, the predominant OH&S-MS, in the oil and gas industry, is based on ISO 18001, although companies may use any OH&S-MS they choose. Prior to ISO 18001, the industry OH&S-MS was initially proposed by the oil industry international Exploration and Production Forum (E&P Forum). E&P Forum was the international association of oil companies and petroleum industry organisations formed in 1974, however it has subsequently been renamed as the International Association of Oil and Gas Producers, (OGP) [28, 44] [29].

Within the various OH&S-MS there are also differences in the definitions and treatment regarding risk perception [143], and risk criteria (acceptability or tolerability and risk estimation) [144-147]. All of these factors can lead to variability in the risk assessment process. As part of the oil and gas industries OH&S-MS, the current recognised standard for hazard identification and risk management for offshore operations is BS EN ISO 17776 – 2002 [148]. In the scope it states,

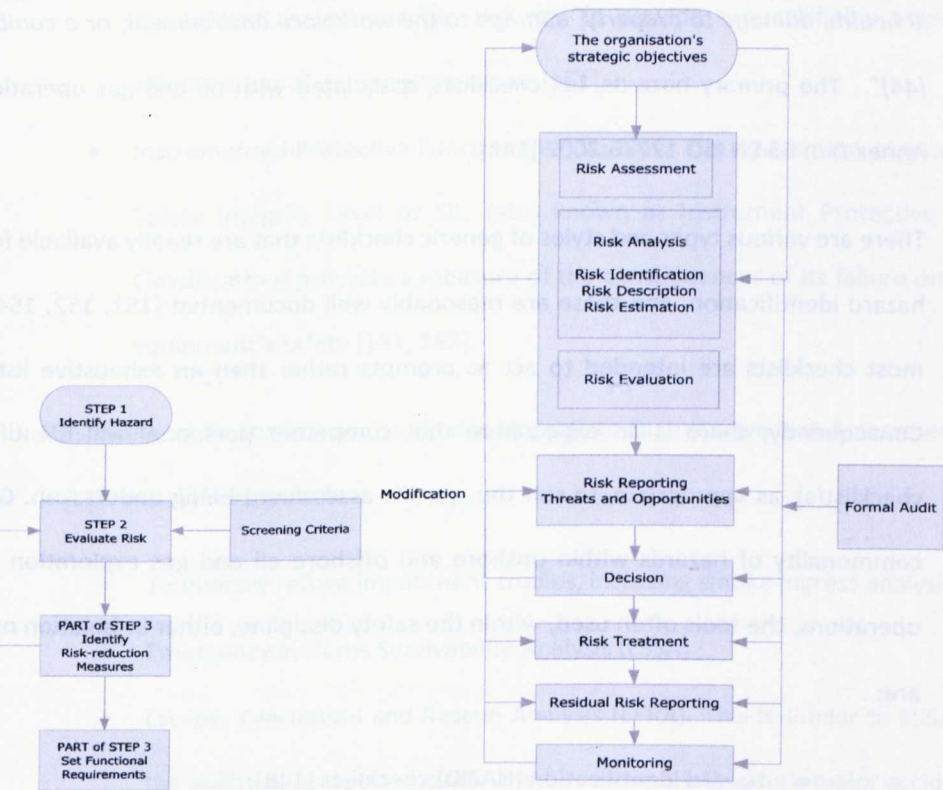
“This International Standard describes some of the principal tools and techniques that are commonly used for the identification and assessment of hazards associated with offshore oil and gas exploration and production activities, including seismic and topographical surveys, drilling and well operations, field development, operations, decommissioning and disposal, together with the

necessary logistical support of each of these activities. It provides guidance on how these tools and techniques can be used to assist in the development of strategies, both to prevent hazardous events and to control and mitigate any events that may arise”.

However, a different, but more detailed, version of the process is published by the The Institute of Risk Management (IRM), The Association of Insurance and Risk Managers (AIRMIC) and ALARM, the National Forum for Risk Management in the Public Sector [149]. In either case, the resource required for risk assessment should be commensurate with the estimated magnitude of the risk.

The process they describe is shown in Figure 18 below.

Figure 18 Processes for risk management



Source BS EN ISO 17776:2002

Source AIRMIC, ALARM, IRM: 2002

The literature covering risk management demonstrates relatively common features and is well documented. However, there is concern about the reliability of risk assessments by project

managers as research has shown that there is often a significant degree of optimism bias and an illusion of control relating to risk perception. Further research is being carried out in this area by the International Institute of Risk and Safety Management in collaboration with Manchester Business School and BP [150]. The primary tools and techniques used in oil and gas risk assessment are described below.

2.5.3 Hazard Identification

Hazard identification is the first, and most important, element in the risk assessment process, simply because if hazards are not identified, then they cannot be risk-assessed.

Hazard is defined as the *“source or situation with a potential for harm in terms of human injury or ill health, damage to property, damage to the workplace environment, or a combination of these [44]”*. The primary hazards, i.e. checklists, associated with oil and gas operations are listed in Annex D of BS EN ISO 17776:2002 [148].

There are various types and styles of generic checklists that are readily available for many types of hazard identification, and these are reasonably well documented [151, 152, 154, 155], although most checklists are intended to act as prompts rather than an exhaustive list of guidewords. Consequently, there is an expectation that competent personnel will identify and modify a checklist(s), as appropriate, to suit the specific assessment being undertaken. Given the relative commonality of hazards within onshore and offshore oil and gas exploration and exploitation operations, the tools often used, within the safety discipline, either in isolation or in combination, are:

- Hazard identification (HAZID) checklists [148];
- Hazard and Operability Studies (HAZOP), which are primarily used to carry out a systematic critical review of process systems [156-160]
- Procedural HAZOP that can be applied to batch or continuous processes to ensure that every step in a procedure is properly considered [137, 148];

- What-If Analysis, commonly called a Structured what-if technique (SWIFT), which is essentially a brainstorming exercise applying similar approaches to HAZID or HAZOP studies but starting with the phase 'what-if' to generate discussion; and
- Failure Modes and Effects Analysis (FMEA) or Failure Modes and Effects Criticality Analysis (FMECA) which is a systematic review of a mechanical system, considering each component in turn and assessing the effects and criticality of failure [161].

Other risk studies generally used in the industry that directly, or indirectly, support safety performance are:

- Reliability, Availability and Maintainability (RAM) studies, which are conducted throughout the oil and gas industry to provide a quantifiable assessment of the effectiveness of an operating asset. [161];
- Instrumented Protective Function (IPF) studies. The assessment of a safety function's Safety Integrity Level or SIL, (also known as Instrument Protective Function, IPF, Classification) provides a measure of the consequences of its failure on the system or equipment's safety [161, 162].

Offshore-specific studies, as specified in 'A guide to Quantitative Risk Assessment for Offshore Installations' [163], include:

- Temporary refuge impairment studies, including smoke ingress analysis ;
- Emergency Systems Survivability Analysis (ESSA) ;
- Escape, Evacuation and Rescue Analysis (EERA). This is similar to ESSA but assesses the ability to escape, evacuate and be rescued, following a major accident event ;
- Hydrocarbon blowout (an incident where formation fluid flows out of the well or between formation layers after all of the predefined technical well barriers or the activation of the same have failed). This is a major incident with a high potential for

multiple fatalities, and loss of the drilling facility, e.g. due to blowouts, riser and pipeline failures;

- Ship collision impact analysis ;
- Structural failures ; and
- Transport accidents, e.g. flying and marine.

The key to a successful assessment is to have sufficient, competent personnel representing the relevant disciplines, e.g. structural, safety, process, production, etc., and with adequate time to properly conduct the assessment to ensure that hazards are identified and their controls or mitigations evaluated. The timing of the study is also critical: too early and the safety implications of subsequent design changes may be missed, too late and it may not be possible to make safety-related changes to improve safety performance.

2.5.4 Major Accident Databases

One of the difficulties experienced during this research was access to non-fee based authenticated databases. Further problems are described below:

- no single definition of a major accident or disaster exists;
- data input for the databases is extremely varied and potentially unreliable;
- construction of databases, due to their search criteria, can yield widely differing results;
- there are delays in data and published reports becoming available;
- some databases can contain duplicates where similar information is derived from a variety of sources; and
- the quantity of the data varies from a single line of text to more than a page.

Access to non-fee paying major accident databases is extremely limited and some free databases that are available have no authentication to validate the data. Descriptions of some available accident databases are given below.

Worldwide Accident Databank (WOAD)

The Den Norske Veritas (DnV) Worldwide Offshore Accident Databank (WOAD) is a collection of offshore accident data with statistical material that has been accumulated since 1975 [164]. It is continuously being updated with the latest information from authorities, official publications and reports, newspapers, databases, rig owners, and operators globally. All WOAD data, reporting and filtering functionality is delivered through a fee-based web application.

UK Health and Safety Executive

Major Hazard Incident Data Service (MHIDAS)

The UK HSE sponsors the Major Hazard Incident Data Service (MHIDAS) which is operated by AEA Technology (AEAT) on their behalf. This information is required by the UK HSE as a regulator. A public access data service based on the MHIDAS accident database was established in 1985. The database contains coded information on reports of some 8000 major accidents which are in the public domain. The database is updated quarterly and is available to users via various media, including compact disc and the internet [165]. Public access is delivered via a fee-based service from AEAT.

Injury and Incident Statistics

The UK HSE also publishes annually the Offshore Injury and Incident Statistics [166]. The annual reports are part of a series of Hazardous Installations Directorate (HID) Statistics Reports covering offshore injury and incident statistics, which continue from previous Offshore Technology Reports from the UK HSE. Data is derived from submissions by oil and gas companies under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR). This is a useful database since it is a statutory requirement to report relevant events, and is therefore scrutinised by the UK HSE. The information is free and publicly-available, and was used in this research.

Hydrocarbon Releases Database

The UK HSE publishes Offshore Injury and Incident Statistics Reports that contain information and trends on offshore hydrocarbon releases. Offshore releases of hydrocarbons are currently reported to the Offshore Safety Division (OSD) as dangerous occurrences under RIDDOR, which became effective offshore on 1 April 1996. The Hydrocarbon Releases (HCR) System contains detailed voluntary information on offshore hydrocarbon release incidents, which is supplementary to that provided under RIDDOR (and previous offshore legislation prior to April 1996) and the database contains reports dating from 1 October 1992 [167]. This database is also scrutinised by the UK HSE, and was used in this research.

Research Reports

Several projects were undertaken by Den Norske Veritas (DnV) and Oil and Gas UK on behalf of the UK HSE, to obtain accident statistics for offshore fixed and floating units on the UK Continental Shelf (UKCS). Four databases having such information about relevant incidents were interrogated. These were:

- The Combined Online Information System (COINS) and ORION (acronym not published but the former Sun Safety System,) held by the UK HSE;
- Offshore Blowout Database held by Stiftelsen for Industriell og Teknisk Forskning, SINTEF, Norway;
- Worldwide Offshore Accident Databank (WOAD, DnV); and
- MAIB accident database (UK Marine Accident Investigation Branch)

As a result of these projects the UK HSE published the following reports which can be freely accessed by the public, and which were used in this research:

- Accidents Statistics for Offshore Units on the UKCS 1990 – 2007, April 2009;

- Accidents Statistics for Offshore Units on the UKCS 1990 – 2006, completed in March 2008;
- Accidents Statistics Fixed Offshore Units on the UK Continental Shelf 1980 – 2005; and
- Accidents Statistics Floating Offshore Units on the UK Continental Shelf 1980 – 2005.

Given that the UK is often used to benchmark global safety activities and the research reports are free and available on the UK HSE website, the data was used in this research.

Major Accident Reporting System (MARS)

The scope of the European Commission (EU) official online reporting system, eMARS, facilitates the exchange of information on accidents and near-misses related to Seveso [96, 169] establishments, i.e. industries where dangerous substances are present in quantities exceeding thresholds set by the EU, and promotes lessons learned among the EU Member States and the Organisation for Economic Co-operation and Development (OECD) countries, as well as the general public. The system contains data on chemical accidents and near-misses reported to the Major Accident and Hazards Bureau (MAHB) by the competent National Authorities under the current and prior Seveso Directives since 1982. The information related to the reported event is entered into eMARS by the EU Member States and OECD Countries themselves. Reporting an event into eMARS is compulsory for EU Member States when a Seveso establishment is involved and the event satisfies one or more of the six criteria set out in the Seveso Directive. The eMARS database has the narrowest scope since it contains only those incidents notified to the EC under the Seveso Directive (or the COMAH Regulations in the UK). The reporting is done on a voluntary basis by those OECD Countries which are non-EU Members. Access is free if registered with the MARS organisation. This database was used in this research.

The Institution of Chemical Engineers (IChemE)

The IChemE provides an Accident Database that has a much broader focus than MHIDAS or MARS. It covers global accidents of all sizes as well as near-misses. The Accident Database is delivered via a fee-based service from IChemE.

This database appears to only provide results up to the year 2000. It is currently (2011) not maintained, although IChemE have plans to restore and update the database. Consequently, it was not used in this research.

The International Association of Oil and Gas Producers (OGP)

This Association has been collecting incident data from member companies since 1985. The database is considered to be the largest database of safety performance in the exploration and production industry. Its principle purpose is to provide the industry with trend analysis, benchmarking, and the identification of areas and activities that should bring about the greatest improvements in performance. Incident data is global and covers both onshore and offshore operations, and member companies and their contractor employees. Access to the Annual Safety Performance Reports is free via the OGP website, and these were used in this research.

The International Association of Drilling Contractors (IADC)

The IADC provides annual safety performance reports, the Incident Statistics Program (ISP), based on compiled data volunteered by drilling contractors worldwide. During 2009, 125 contractors, representing approximately 78% of the worldwide oil and gas drilling rig fleet, participated in providing data. The annual ISP reports are freely available online and were used in this research.

Offshore Reliability Data (OREDA)

OREDA is a project organisation with eight oil and gas companies as members (2009). It collects and collates reliability data and provides a databank. The data is derived globally but OREDA is

also a forum for the exchange of reliability methods and experience within the oil and gas industry. Its general objectives are stated as:

- *“To improve safety by providing experience and data on risks;*
- *To improve reliability and availability by the use of reliability data to select the most reliable equipment and configurations, and to reveal design weaknesses;*
- *To improve maintenance effectiveness by using failure data to refine maintenance strategies; and*
- *To enhance industry reputation by demonstrating a high degree of understanding of equipment performance and characteristics”.*

ORDEA has issued five handbooks (in the years 1984, 1992, 1997, 2002 and 2009) that have been sold in over 50 countries, and has developed an ISO Standard based on the OREDA concept (ISO 14224) [162]. The 2009 version has two volumes and costs (2011 prices) NOK 4250 per copy (Volume 1 or Volume 2) and NOK 6250 for both handbooks [171]. Given the cost and its limited applicability for this research, it was not used.

Stiftelsen for Industriell og Teknisk Forskning (SINTEF)

SINTEF collects, collates and analyses Offshore Blowout Data. Blowout and well release frequencies are established and updated each year [172]. The data is derived from the geographical areas of the U.S. Gulf of Mexico Outer Continental Shelf, Canada East Continental Shelf, and the North Sea. SINTEF released the Offshore Blowout Database as an Internet database in 2009. The database includes information on 573 offshore blowouts/well releases that have occurred world-wide since 1955.

The blowouts/well releases are categorised by several parameters, emphasising blowout causes. The database and annual report are confidential and only accessible for the project sponsors. Access to the database was made available to the author by one of the participating organisations, and it was used in this research.

Lees

A source of data is available in the three-volume set, '*Loss Prevention in the Process Industries – Hazard Identification, Assessment and Control*, edited by Frank P. Lees'. The first edition was published in 1980, and the third, and current (2011) was published in January 2005. The second edition, published in 1996 was consulted in this research but the data was too limited and thus was not used [135].

Oil Rig Disasters

This is a free online website, and although unauthenticated, is a useful source of information [173]. The information corresponds reasonably well with authenticated data (e.g. from the data sources described above), and provides information sources that can easily be validated. Consequently it was used in this research. However, it is limited to drilling rig disasters only.

2.5.5 Quantitative Consequence Analysis (QRA)

The literature covering primary major hazards associated with offshore oil and gas exploration and exploitation relates to:

- Hydrocarbon release through processing, blowout, riser and pipelines;
- Non-process fires;
- Structural failures;
- Transport/logistics failures and collisions, for marine and aviation operations; and
- Occupational events.

More specifically, in terms of hydrocarbon releases, there is ample literature covering phenomenological and computational fluid dynamic (CFD) modelling [174, 175]. However, the use of models, especially those covering fire and explosion, presents problems, particularly in the offshore sector. As the models become more sophisticated, and designs are re-modelled at later dates using newer software, over or under design problems may be revealed. These issues may be

difficult to reconcile, as offshore designs are generally optimised to produce minimum footprints and structures to reduce initial construction and subsequent operational and maintenance costs. Often, elements of contingency are not provided for in initial design specifications, primarily due to the high capital costs.

There are various software models that support major hazard analysis and these are listed in Table 4. Interrogation of the models in the publication, “*The Guide to Quantitative Risk Assessment for Offshore Installations*” indicates that many have been updated to reflect continuous improvements in their accuracy and reliability, and to accommodate newer computer operating platforms [163].

Table 4 Software used in the oil and gas industry for risk assessment

Category	Example of Software	Supplier
General Offshore Risk Analysis	Offshore Hazard and Risk Analysis (OHRAT) Toolkit, superseded by Neptune	Den Norske Veritas Ltd
Fire and Gas Explosion Modeling	FRED	Shell International
Explosion Modeling	AutoReaGas (CFD)	Century Dynamics Ltd
Evacuation, Escape and Rescue Analysis	EVAC	Saftec UK Ltd
Populations Databases	North Sea Facts Database	Oilfield Publications Ltd
Reliability Analysis	CARA	Den Norske Veritas Ltd
Event Tree Analysis	LOGAN	R M Consultants Ltd

The issue is not adequately covered in current literature, and requires further research to identify the implications, especially when applying an inherently safe approach to design.

2.5.5.1 Frequency Analysis

Frequency analysis involves estimating the likelihood of the failure case under assessment. There are generally two basic forms in which the analysis can be expressed:

- Frequency: the expected number of occurrences of the event per unit time (usually a year); and

- Probability: the probability of an event occurring in a given time period or the conditional probability given that a previous event has occurred. A probability is dimensionless, and in the range 0 – 1.

The primary approaches to determining frequency are:

- Using historical frequency data;
- Fault Tree Analysis (FTA) [177], that requires breaking down an event/failure into component causes and estimating the frequency of each component event/failure, using a combination of event/failure data and engineering judgement
- Event Tree Analysis (ETA) [178], which is similar to FTA but starts at the event/failure and develops this into an assessment of the potential outcomes.

The sources of information include accident databases, published accident frequency analysis, published risk assessments, reliability data, and accident data collections [179-181]. Given that the technology changes, the types of analysis, e.g. FTA & ETA, can be subjective and the data may be inaccurate for various reasons, in which case, as for consequence analysis, the results usually have to be treated with caution.

2.5.5.2 Qualitative Consequence and Frequency Analysis

Another method involves working out a risk level by categorising the likelihood of the harm and the potential severity of the harm, and then plotting these two risk-determining factors against each other in a risk assessment matrix (RAM), Figure 19.

Qualitative risk assessment, e.g. using a RAM, is useful where the data needed for Quantitative Risk Assessment (QRA) is unavailable, such as in new or novel designs, or where risks are not likely to constitute a major accident hazard and the need for QRA is not justified. However, it is more subjective and therefore a team of suitably-competent personnel covering all relevant disciplines is generally required to obtain realistic results.

Getting this wrong could result in applying unnecessary controls, or failing to take important ones into consideration. The literature shows several variations of risk assessment matrix, but, in general, these relate to the expansion and description of the categories of severity and frequency, and therefore lead to wide variations in application. Figure 19 shows an example of a Risk Assessment Matrix.

Figure 19 Risk Assessment Matrix (RAM)

		Potential Severity of Harm		
		Slightly Harmful	Harmful	Extremely Harmful
Likelihood of Harm Occurring	Highly Unlikely	Trivial	Tolerable	Moderate
	Unlikely	Tolerable	Moderate	Substantial
	Likely	Moderate	Substantial	Intolerable

Source: Health and Safety Executive, Risk Management, FAQs

2.5.6 Evaluation of risks and Screening Criteria

2.5.6.1 Introduction

Risk is primarily confined to the risk to people, although most risk assessment can include risks to assets, the environment and reputation. In many respects, any major accident will affect all these areas and therefore by protecting people there are indirect benefits in minimizing asset, environmental and reputational impacts. This research is only concerned with situations where people are exposed to risk.

Much of the literature is based on the principles established by the UK HSE in deciding how to assess both the tolerability and level of risk inherent in oil and gas exploration and exploitation [59].

In the UK, the requirement for risks to be 'as low as is reasonably practicable' (ALARP) is fundamental and applies to all activities within the scope of the UK Health and Safety at Work, etc. Act 1974 [45]. The UK HSE considers that duties to ensure health and safety so far as is reasonably practicable ('SFAIRP') and duties to reduce risks as low as is reasonably practicable ("ALARP") require the same set of tests to be applied. There is little legal guidance defining what reducing risks as low as is reasonably practicable means since the [U.K.] Court of Appeal held that;

"... in every case, it is the risk that has to be weighed against the measures necessary to eliminate the risk. The greater the risk, no doubt, the less will be the weight to be given to the factor of cost"

and

"'Reasonably practicable' is a narrower term than 'physically possible' and seems to me to imply that a computation must be made by the owner in which the quantum of risk is placed on one scale and the sacrifice involved in the measures necessary for averting the risk (whether in money, time or trouble) is placed in the other, and that, if it be shown that there is a gross disproportion between them - the risk being insignificant in relation to the sacrifice - the defendants discharge the onus on them".

The HSE only expect organisations to address those risks that are a reasonably foreseeable cause of potential harm so as to avoid unnecessary attention on potentially abstract risks. In this context the assessment of risk has to consider employees, the self-employed, and members of the public that may be affected by an incident caused by an organisation's activities.

The ALARP principle is based on the 'reversed onus of proof' that requires all identified risk reduction measures to be implemented, unless it can be demonstrated that there is a gross disproportion between costs and benefits. The determination of what is grossly disproportionate is often carried out using cost-benefit analysis (CBA) and various financial values are used to represent the statistical loss of life, or Implied Cost of Averting Fatalities (ICAF) [92, 182] [183] [163].

The financial values used can vary according to whether the risk is to individuals, such as in the transport sector or rail industry, or is much higher, and there is the potential for multiple fatalities, as in the oil and gas industry [184] [185]. However, it is also argued that the financial criteria used, such as net present value (NPV), do not adequately reflect the risks and uncertainties [186, 187]. It is also argued that risk criteria should not be used, perhaps because they are too prescriptive, and that judgments should instead be made using the concept of cost-effectiveness [188]. However, the use of cost-effectiveness is likely to be as, if not more, subjective and controversial.

The sacrifice discussed by the UK HSE, as part of ALARP decision-making, relates to the measures that an organisation could take to prevent or mitigate the potential harmful effects of a particular risk. Measures, in this context, mean time, money and effort. However, the UK HSE argue that the financial viability of a particular project is not a legitimate factor in the assessment of its safety costs, i.e. organisations should not take into account their size and financial position when making judgments on whether risks have been reduced ALARP, and that the benefits gained by organisations as a result of effective and efficient implementation of health and safety measures should be offset against the costs they incur.

The general principle, applied by the UK authorities and UK courts when considering whether ALARP has been reached, is on the basis of proportionality, and therefore the greater the risk, the less weight will be given to the factor of cost. However, the UK HSE has not formulated an algorithm which can be used to determine the proportion factor for a given level of risk. The extent of the bias must be argued by organisations on a case-by-case basis. However, there is some criticism that, for example, the current UK offshore safety case regime indirectly fails to present an ALARP case, as there is no explicit requirement in the regulations to provide a robust case clearly demonstrating how an organisation's arrangements lead to a continued safe operation [189].

Societal concerns can arise when the realisation of a risk impacts on society as a whole. The public and political impact may produce an adverse response (which has its origins in the public aversion to certain characteristics of the hazards concerned, e.g. nuclear). The harm which results is a loss of confidence by society in the provisions and arrangements in place for protecting people, and, consequently, a loss of trust in the regulator. This was an outcome from the Piper Alpha Inquiry, when the role of the regulator was transferred from the Department of Energy to the Health and Safety Executive, and similarly, the transfer of regulatory duties following the Deepwater Horizon investigation. This situation often arises when large numbers of people are killed at one time, where potential victims are particularly vulnerable (such as children), or where the nature of the risks inspires dread (such as long-term or irreversible effects).

It is often possible to transfer risks, e.g. from one phase of a development lifecycle to another. However, this should be seen in the context of a holistic view of the overall development lifecycle. Therefore transferring risk may not constitute ALARP when considered over the development lifecycle. For example, transferring a risk from design may not be effective, and probably not cost-effective, if the subsequent controls required rely on lower order controls. Furthermore, the costs of making changes to a design during the operational phase are likely to be significantly higher than during the design and construction phases. It should be noted that risks may also be transferred both internally and externally. For example, it is argued that in the case of the Flixborough disaster, (an explosion at a chemical plant close to the village of Flixborough, England, on 1 June 1974, which killed 28 people and seriously injured 36) [36], the process was replaced by one which was less hazardous, but which used a raw material manufactured elsewhere by an equally hazardous process [190]. Assessments require that organisations identify the hazards in their workplace, determine who might be harmed and how, evaluate the risk from the hazards, and decide whether the existing control measures are suitable and sufficient, or whether more should be done. There are various tools and techniques for the evaluation of risk which are common to the industry, although it is suggested that this is not the case for determining inherent

safety [191]. Similarly, most organisations, including global oil and gas companies, have similar hazards and therefore similar risks, requiring broadly similar controls, although the focus may vary between organisations. Consequently, there are a number of industry standards that have been developed which provide good, if not best, practice. These standards are normally accepted by the UK HSE, if properly implemented, as reducing the risks to ALARP [147]. Nevertheless, this still has to be demonstrated by an organisation, to be the case.

During the design stage there may be a number of options available to meet specifications, and therefore choices have to be made. Often, for large projects the project performance criteria comprise a combination of factors such as cost, schedule, and health, safety and environment. Therefore judgments have to be made about which combination of these options delivers an overall ALARP case, when assessed against lifecycle criteria. This issue can be more difficult with brownfield, compared to greenfield, projects as there are generally implications associated with retrofitting existing plant in order to interface with a new system. Given the above vagaries associated with risk assessment and screening criteria, the literature is similarly vague in its evaluation of risk tolerability, although there is guidance as discussed below.

2.5.6.2 Quantitative Risk Criteria

The basis for quantitative risk criteria is derived from the nuclear industry, and the Report *"Tolerability of Risk of Nuclear Power Stations"* [145]. Some of the key issues identified in the Report are:

- *"Tolerability' does not mean 'acceptability'. It refers to a willingness to live with a risk so as to secure certain benefits, and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review, and reduce still further if and when we can. For a risk to be 'acceptable' on the other hand, means that for the purposes of life or work, we are prepared to take it pretty well as it is.*

- Risk is the chance that something adverse will happen
- There is no such thing as 'nil risk'.
- We can distinguish the general levels of risk that individuals accept for a personal benefit (such as pay at work) and we can also see the level of risk we usually ignore or regard as negligible”.

These levels are broadly described in terms of average figures. Table 5 illustrates typical comparative risk levels for certain activities.

Table 5 Levels of Fatal Risk (average figures approximated)

Per annum	Description
1 in 100	Risk of death from five hours of solo rock climbing every weekend
1 in 1000	Risk of death due to work in high risk groups within relatively risky industries such as mining
1 in 10,000	General risk of death in a traffic accident
1 in 100,000	Risk of death in an accident at work in the very safest parts of industry
1 in 1 million	General risk of death in a fire or explosion from gas at home
1 in 10 million	Risk of death by lightning

Source: Tolerability of Risk of Nuclear Power Stations’

There are also variations in risk criteria used in other countries. These are shown in Table 6.

Table 6 International Risk Criteria

	UK	Hong Kong	The Netherlands	Australia (New South Wales)
Individual risk de minimus (Worker) (negligible)	1 in 10,000	Not used	Not used	Not used
Individual risk de minimus (Public)	1 in 1,000,000	Not used	1 in 100,000,000	Not used
Individual risk de manifestus (Worker) (intolerable)	1 in 1000	Not used	Not used	Not used
Individual risk de manifestus (Public)	1 in 10,000	1 in 10,000	1 in 1,000,000	1 in 1,000,000

Source: Government tolerable risk criteria summary [146]

De minimus means a negligible risk

De manifestus means an unacceptable risk

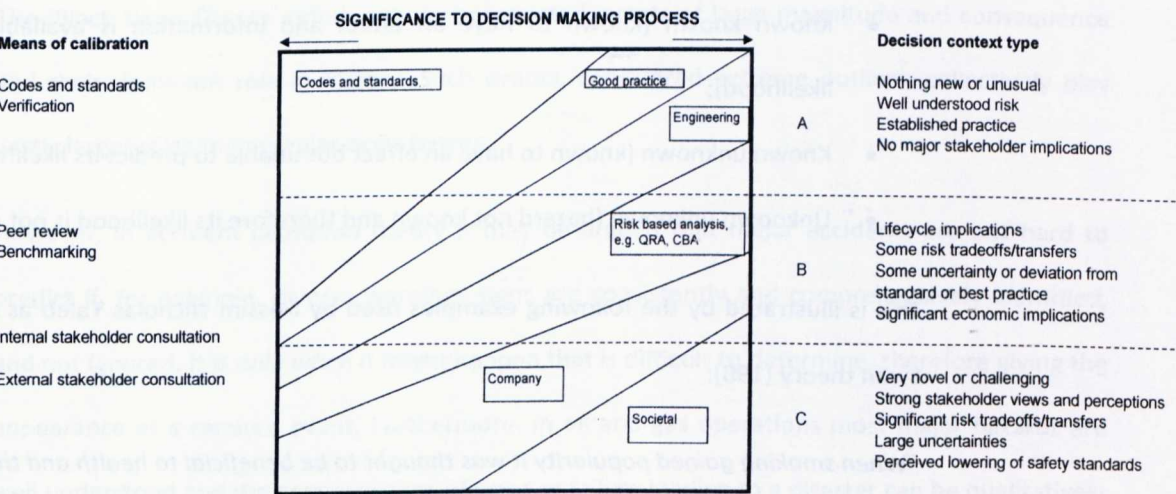
The literature demonstrates significant variation in approach and ranges in risk tolerability criteria.

2.5.7 A Decision Making Framework used in the Oil and Gas Industry

Guidelines have been produced by the UK Offshore Operators Association (UKOOA), now called Oil and Gas UK, that describes a framework to assist risk-related decision making, primarily where the risks concerned are those associated with major accident hazards [192]. The framework takes account of the various business, technical and social factors that influence decision-making and is intended to be transparent and fully auditable. However, the guidelines are non-prescriptive and can reflect the values of different companies. Its primary focus is to cover major safety-related decisions during the design, operation and abandonment of offshore installations, although it has wider applicability.

Since it is stated that the guidelines are industry good practice, then the application of the guidelines should contribute to an ALARP case in the decision-making process (Figure 20).

Figure 20 A decision support framework for major accident hazard safety



Source: A Framework for Risk Related Decision Support, Oil and Gas UK

In a speech to a Process Safety forum in London, the chairman of the UK HSE, Judith Hackitt, stated there is an “unfortunate propensity among the process industries such as oil, and gas production and chemicals manufacture to emphasize difference as a reason for not recognizing

what they have in common and working together". She continued, "Process safety management and leadership is an area where this makes absolutely no sense and where we need to maximize the sharing of knowledge and learning". This speech was triggered in part by UK HSE analysis which showed that in the year 2010 – 2011 there had been 105 loss of containment incidents categorised as dangerous occurrences under RIDDOR, more than half of which were considered to be precursor events for potential major accidents [193]. The guidelines can also be used in combination with other decision-making aids such as Multi-Attribute Utility Analysis (MAUA) [194, 195], Analytical Hierarchy Process (AHP) [196] or decision trees [197]. Naturally these guidelines need to be used by competent personnel, as with all HSE tools and techniques.

2.5.8 Assessing the risk for low frequency, high consequence events

How does the industry deal with rare and extreme occurrences if an event is calculated to occur once every 1000 or 10,000 years, when typically oil and gas facilities have a design life of 20 – 40 years? We anticipate it happening but it could occur at any time during that period. In Black Swan theory (see 2.5.9) any future event falls into one of three categories:

- Known known (known to have an effect and information is available to predict its likelihood);
- Known unknown (known to have an effect but unable to predict its likelihood); and
- Unknown unknown (hazard not known and therefore its likelihood is not relevant).

This is illustrated by the following examples used by Nassim Nicholas Taleb as part of his Black Swan theory [198]:

"When smoking gained popularity it was thought to be beneficial to health and therefore it was an 'unknown – unknown', but when a link to lung cancer was discovered it became a 'known-unknown'; in other words it was known to have an effect but the likelihood was unknown. As the link became more fully understood, it moved towards a 'known-known'. In the case of earthquakes, we know they occur but not when, i.e. a 'known-unknown'. The nuclear industry has

not been around for a million years and no anthropologic structure is designed to last that long so expressing the reliability of a plant in terms of one event per million years demonstrates some weaknesses in the validity of the assessment. It is argued that there is a tendency to underestimate the probability of failure and that the edges of probability graphs are bigger than equations predict (i.e. where the probability of an event occurring can range anywhere from just above 0% to just below 100%. It cannot be exactly 100%, because then it would be a certainty, not a risk, and it cannot be exactly 0%, or it wouldn't be a risk). However, these are the areas in which the most extreme events sit and may constitute some of the 'unknown-unknown' risks. Essentially, an 'unknown-unknown' is one that has not been considered at all, until it happens, when it stops being an unknown".

2.5.9 Black Swan Theory

Taleb's Black Swan Theory or Theory of Black Swan Events is a metaphor that encapsulates the concept that an event is a surprise (to the observer) and has a major impact. After the fact, the event is rationalised by hindsight.

The 'Black Swan Theory' refers only to unexpected events of large magnitude and consequence and their dominant role in history. Such events, considered extreme outliers, collectively play vastly larger roles than regular occurrences.

However, in accident causation theory it may be argued that major accidents are not hard to predict if, for example, diverse warnings signs are consistently and comprehensively identified, and not ignored. It is only *when* it might happen that is difficult to determine, therefore giving the appearance of a random event. Furthermore, in oil and gas operations most major hazards are well understood and the consequences of error or failure leading to a disaster can be qualitatively or quantitatively determined, using, for example, computational fluid dynamic (CFD) models. Also, the impact of recent disasters, e.g. Deepwater Horizon, is well documented and publicised in various media, ensuring they are well developed and distributed in the public domain.

2.6 Major Accidents

2.6.1 Introduction

The European Commission (EC) recognises that the scale and characteristics of recent offshore accidents and near-misses demand action, and that they expose the disparity between the increasing complexity of oil and gas operations and inadequacies in current risk management practices. This includes wide variations in safety performance and attitudes, the challenges facing the regulators to provide suitable support, lack of transparency, and data sharing. Consequently, in October 2011, the EU proposed additional measures to reduce the risks of major accidents and to limit their consequences [69].

While there are variations in the definitions of major accident, it is proposed to use two definitions that are widely applied in the UK. The first is derived from the Control of Major Accident Hazards Regulations (COMAH) 1999 [96], which is applied to qualifying onshore installations, but not to offshore installations, and the second from the Offshore Installations (Safety Case) Regulations 2005 [200].

2.6.2 Onshore and Offshore Major Hazards

COMAH and its predecessor (the Control of Industrial Major Accident Hazards, CIMAH [201]) were initiated after the Seveso disaster. This was an industrial accident that occurred on July 10, 1976, in a small chemical manufacturing plant north of Milan in Italy. It resulted in the highest known exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in residential populations, which gave rise to numerous scientific studies and standardised industrial safety regulations. This also led to much harsher Industrial safety regulations, encompassed in the Seveso Directive, that were passed in the European Community in 1982. The Seveso Directive was updated in 1999, and amended again in 2005, and is currently referred to as the Seveso II Directive (or COMAH Regulations, in the United Kingdom) [202].

The Seveso Directive was also a response to previous serious onshore chemical or petrochemical incidents such as the explosion of cyclohexane in the Nypro Ltd. plant at Flixborough [36]. During the next two years, three additional serious chemical accidents occurred within the European Community: these were at Beek [203], Manfredonia [204], and finally Seveso. The Seveso Directive requires that the workers and general public are made aware of the hazards that threaten them, and how the industry responsible for the hazard(s) will manage the residual risks. However, this 'need to know' principle is not the same as the 'right to know' principle that is widely adopted in the U.S., i.e. the status of 'need' is determined by the authorities and is not a right of citizens [205].

Similar to the motivation for the Seveso Directives, the offshore safety case regime evolved from the Inquiry into the Piper Alpha disaster. This requires that the operator of a hazardous offshore installation demonstrates to the regulatory authority the safe design and operation of the installation rather than compliance with the regulations. The offshore safety case is broadly similar to that required for onshore installations but with key differences as described below. Qualifying, in relation to the COMAH Regulations, means an establishment having any substance, specified in Schedule 1 of the regulations, present at, or above, the qualifying quantity. There are two thresholds, known as lower-tier and top-tier, and the application of either tier is dependent on the quantities of dangerous substances at an establishment. Lower-tier operators must take 'all measures necessary' to prevent major accidents and report any that do occur. An important duty of lower-tier operators is the preparation of a Major Accident Prevention Policy (MAPP). This duty reflects the vital role of management systems in accident prevention [65]. If any top-tier threshold is equalled or exceeded, the operator must also comply with additional regulations and prepare and submit a written safety report, analogous to an offshore safety case.

The COMAH regulations define major accident as, *“an occurrence (including in particular, a major emission, fire or explosion) resulting from uncontrolled developments in the course of the operation of any establishment and leading to serious danger to human health or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances”*.

The qualifying criteria for offshore major accidents are set out in The Offshore Safety Case Regulations [200] that define major accident as,

- *“a fire, explosion or the release of a dangerous substance involving death or serious personal injury to persons on the installation or engaged in an activity on or in connection with it;*
- *an event involving major damage to the structure of the installation or plant affixed thereto or any loss in the stability of the installation;*
- *the collision of a helicopter with the installation;*
- *the failure of life support systems for diving operations in connection with the installation, the detachment of a diving bell used for such operations or the trapping of a diver in a diving bell or other subsea chamber used for such operations; or*
- *any other event arising from a work activity involving death or serious personal injury to five or more persons on the installation or engaged in an activity in connection with it”*.

Noteworthy are the key differences between the definitions. The COMAH definition considers the danger to people, the environment and the public, while the offshore regulations definition does not need to consider the public, but neither does it consider the environment. Furthermore, the offshore regulations are also specifically required to consider the structure of the installation and helicopter and diving operations.

Similarly, there are also guidelines for the global development of safety cases for onshore and offshore drilling units, produced by the International Association of Drilling Contractors [206-208]. However, in most cases, national laws take precedence over industry guidelines.

2.6.3 Offshore Independent Certification and Verification

2.6.3.1 Certification

Prior to 1988, offshore installations were subject to the requirements of obtaining a five-yearly certificate of fitness (CoF). The role of assessing the fitness-for-purpose of offshore installations for continuing operations rested with a certifying authority (CA), which was appointed by the regulator. This role consisted of assessing inspection techniques and results, and overseeing repairs and technical reassessment as needs arose, subject to technical guidance and survey requirements laid down in statute, to qualify for a CoF [116]. The guidance was first published by the Department of Energy in 1974, to support the Offshore Installations (Construction and Survey) Regulations 1974 to provide a consistent basis for the certification of offshore installations by Government-appointed certifying authorities [116]. The guidance was regularly updated to keep up with evolving technical knowledge and the fourth and final edition was published in 1990. The UK HSE withdrew the guidance from publication in June 1998 at the end of the certification regime.

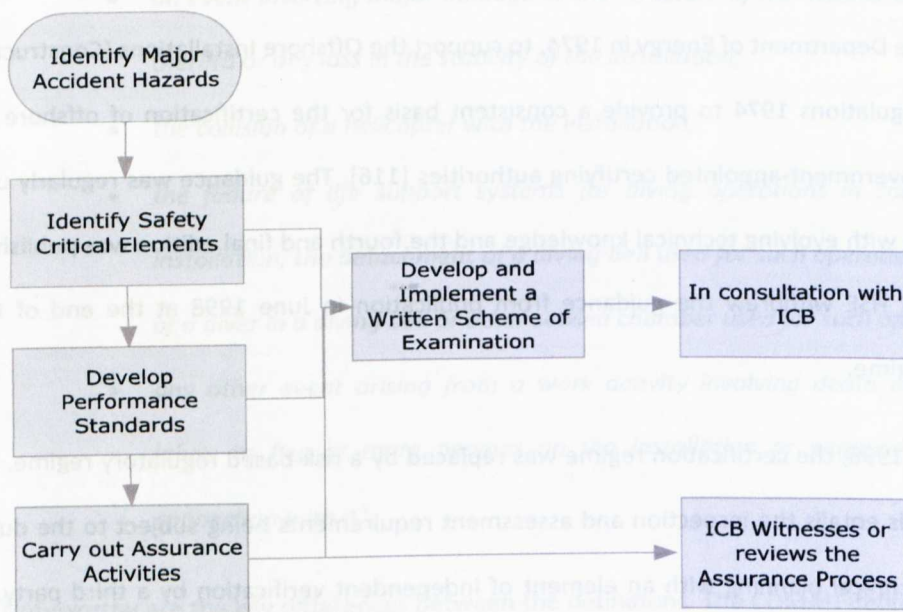
In 1998, the certification regime was replaced by a risk-based regulatory regime, i.e. Verification. This entails the inspection and assessment requirements being subject to the duty holder's own technical planning with an element of independent verification by a third party. The results of such arrangements are not required to be automatically reported to the regulator.

2.6.3.2 Verification

The duty holder (i.e. the operator for a fixed installation and the owner of a mobile installation), for the life of an installation, from design through the various lifecycle phases to decommissioning and dismantlement, has to ensure that there is a suitable written scheme, called a verification

scheme, which makes certain that safety critical elements are suitable and remain in good repair and condition, Figure 21. In this context, duty holders have a statutory duty to control the risks of a major accident as defined in the Offshore Installations (Safety Case) Regulations 2005 (SCR05) [200]. Verification must ensure that safety critical elements and the Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (PFEER) specified plant are initially suitable and remain suitable for the life of the installation [126]. Duty holders also have a further duty under SCR05 to put in place and keep under continual review a verification scheme, by means of which assurance is obtained from an independent competent body or person (ICB/ICP). This is to ensure that safety critical elements and PFEER specified plant are suitable and remain suitable for the life of the installation.

Figure 21 Typical Verification Scheme



The ICP can work for the organisation but have to be sufficiently impartial and objective in their judgment and have independence from pressures, especially of a financial nature. They should not verify their own work, and their management lines should be separate from those whose work they are checking e.g. the independent person's management chain should not include the management responsible for either the work being verified or for meeting production targets.

2.6.3.3 Safety Critical Elements (SCEs)

Safety Critical Elements (SCEs) are defined through the following:- *“Any structure, plant, equipment, system (including computer software) or component part whose failure could cause or contribute substantially to a major accident is safety-critical, as is any which is intended to prevent or limit the effect of a major accident. The term 'contribute substantially to a major accident' is intended to include within the category of 'safety-critical element' those parts whose failure would not directly cause a major accident but would make a significant contribution to a chain of events which could result in a major accident”*. In order to be regarded as a suitable written scheme, the Verification scheme must give assurance that the safety critical elements:

- a) are (or, where they remain to be provided, will be) suitable; and
- b) where they have been provided, remain in good repair and condition.

2.6.3.4 Performance Standards

Performance standards, in the context of SCEs, ensure that the SCEs provide functionality, availability, reliability and survivability, and contain detailed acceptance criteria and contingency actions when the performance criteria are not met.

2.6.4 Disaster reduction

While not specific to technological disasters, the United Nations (UN) has assessed the current risks associated with natural disasters such as earthquakes, tsunamis, floods and droughts [209]. They state that their causes and impacts are increasingly better understood but governments have yet to find a way of reducing and managing the risks they pose.

In some respects this is analogous to the rare but high-consequence technological disasters encountered in the petrochemical business, in that many of the immediate and underlying causes are understood but they continue to occur. The following observations are made:

- Countries with weak governance are likely to find it difficult to address underlying risk drivers. This is similar to the disasters at Texas City (2005) and Deepwater Horizon where regulator failures were identified as contributory factors;
- Extreme hazards and events are not seen as synonymous with extreme risks, as countries with similar hazards manage the resultant risks differently. In oil and gas operations, the hydrocarbon hazard is managed differently between countries, organisations, and in some cases, within the same company ;
- The main opportunities for reducing risk lie in reducing vulnerability. The United Nations believes this can be achieved by addressing the underlying causes through strengthened governance. In oil and gas, improvements in audits and reviews are also seen as crucial to improving safety performance;
- Both individuals and governments seem to discount low-probability future losses and are therefore reluctant to invest in disaster management. Accounting for potential disaster losses does not guarantee greater investment but it may enable a more transparent assessment of liabilities. Equally, in the oil and gas industry the economic effects of disasters such as Deepwater Horizon, may need to be more weighted when making policy decisions about resource allocation;
- Historical evidence shows that societies have always accepted a degree of risk into their technological systems, urban infrastructure and cosmology. However, the funds for disaster reduction management (DRM) often compete with other priorities for limited resources, whereas the UN propose that DRM must be seen as an integral part of local government, but there needs to be political commitment and suitable financial provision to deliver resilience. Similarly, safety management has identical issues.

2.7 Historical Safety Performance of the oil and gas industry

2.7.1 Measuring performance

Oil and gas companies, and other organisations, such as the Oil and Gas Producers (OGP) Association [210] and the UK HSE [211], use various indicators to measure performance [212, 213]; a role shared with OH&S-MSs, so that judgments can be made about the implementation and effectiveness of the arrangements (strategies, processes and activities) for controlling risk, Table 7 [28, 32, 44].

Table 7 Injury-based Safety Performance Indicators used by OGP, IADC and HSE

Key Performance Indicator (KPI)	OGP	IADC	HSE	
No. of Fatalities	✓			
Fatal Accident Rate (FAR)	✓	✓		The number of fatalities per 10 million exposure hours
Fatal Incident Rate (FIR)	✓			The number of fatal incidents per 10 million exposure hours
Fatal Injury Rate			✓	The number of fatal incidents per 100, 000 exposure hours
Major Injury ^a Rate			✓	The number of major injuries per 100,000 exposure hours
Fatal Injury Rate plus Major Injury Rate			✓	See above
Over 3 Day Injury Rate			✓	Lost Time Injury resulting in at least three days off work
Lost Time Injury Frequency (LTIF)	✓	✓		Lost Time Injury (LTI) is an injury resulting in at least one day off work and the frequency is the number of fatalities plus the number of LTIs per one million exposure hours
Total Recordable Incident (case) Rate	✓			Total Recordable Incident Rate is the number of fatalities plus LTIs plus RWDCs plus Medical Treatment Case (MTCs – see below) per one million exposure hours
Restricted Workday Case (RWC or RWDC) plus LTIF	✓			Restricted Workday Cases are injuries and occupational incidents that are severe enough to prevent a person from performing normal duties, but not so severe that lighter duties cannot be performed. The rate is RWCs plus LTIs per one million exposure hours.
Medical Treatment Incident Rate (MTC)		✓		Any work- related injury or illness requiring medical care or treatment beyond first aid (regardless of the provider of such treatment) that does not result in a Restricted Work Case (RWC) or Lost Time Incident (LTI). The rate is based on the number of MTCs per 200, 000 exposure hours
Restricted Work Incidence Rate		✓		Number of RWCs per 200, 000 exposure hours
Lost Time Incidence Rate		✓		Number of fatalities plus LTIs per 200, 000 exposure hours
DART Incidence Rate (Days Away from work or Restricted Time/work)		✓		DART Incident Rate is the number of Fatalities plus LTIs plus RWCs per 200, 000 exposure hours
Recordable Incidence Rate		✓		Recordable Incident Rate is the number of fatalities plus LTIs plus RWCs plus MTCs per 200, 000 exposure hours
DART Frequency Rate		✓		DART Frequency Rate is the number of Fatalities plus LTIs plus RWCs per one million exposure hours
Recordable Frequency Rate		✓		Recordable Frequency Rate is the number of fatalities plus LTIs plus RWCs plus MTCs per one million exposure hours

^aMajor Injury' is defined in the guide to the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 [214]

Measuring performance is an essential requirement of an OH&S-MS to help achieve one of its principle aims: that of continuous and sustainable improvement in safety. The Safety Policy should include a commitment to the prevention of injury and ill health and continual improvement in OH&S management and OH&S performance.

The OH&S-MS should ensure that reports on the performance of the OH&S management system are presented to top management for review and used as a basis for improvement of the OH&S management system; it should establish, implement and maintain a procedure(s) to monitor and measure OH&S performance on a regular basis. Table 8 is used by the UK HSE and lists the non-injury-based KPIs. KPIs should not be confused with Critical Success Factors (CSFs) that are, literally, the factors that are critical to success but are not necessarily measures of performance [215].

Table 8 Non-Injury-based Safety Performance Indicators used by HSE

Key Performance Indicator (KPI)	Description
Number of Major Hydrocarbon Releases	"Potential to quickly impact outwith the local area, e.g. affects the Temporary Refuge (TR), escape routes, and escalates to other areas of the installation, causing serious injury or fatalities." A major leak, if ignited, would be likely to cause a "major accident", i.e. it would be of a size capable of causing multiple casualties or rapid escalation affecting TR, escape routes, etc.
Number of Significant Hydrocarbon Releases	"Potential to cause serious injury or fatality to personnel within the local area and to escalate within that local area, e.g. by causing structural damage, secondary leaks or damage to safety systems." A significant leak, if ignited, might have the potential to cause an event severe enough to be viewed as a "major accident" or be of a size leading to significant escalation within the immediate area or module.
Number of Minor Hydrocarbon Releases	"Potential to cause serious injury to personnel in the immediate vicinity, but no potential to escalate or cause multiple fatalities." A minor leak, even if ignited, would not be expected to result in a multiple fatality event or significant escalation, but could cause serious injuries or a fatality local to the leak site or within that module only.

The KPIs demonstrate, on a global or national level, that the KPIs used are reactive (i.e. lagging or post-incident) as opposed to proactive (i.e. leading or pre-incident, preventative measures) forms of KPI.

The UK HSE guide to key performance indicators [216] suggests that by setting focused leading and lagging indicators, the information obtained will provide an early warning when the systems paid for and implemented, and relied upon for the integrity of business, start to go wrong. However, this is potentially misleading, since, by definition, reactive indicators mean that something has already gone wrong and this could result in business failure, depending on the severity of the event, before an organisation has time to react. Although it assumes a relationship between leading, Table 9, and lagging indicators that may not be recognised, the literature presents cases for using both forms of measurement, but they are generally dominated by KPIs only relevant during the operational phase of a development.

Table 9 Process Safety Leading Indicators

Leading Indicator	Options ¹	Means of Measurement
Mechanical Integrity	A	(Number of inspections of safety critical items of plant and equipment due during the measurement period and completed on time /Total number of inspections of safety critical items of plant and equipment due during the measurement period) x 100 %.
	B	(Length of time plant is in production with items of safety critical plant or equipment in a failed state, as identified by inspection or as a result of breakdown/Length of time plant is in production) x 100%.
Action Items Follow-up		(Number of past due and/or having approved extension of process safety action items/Total number of active or open action items) x 100 %.
Management of Change (MOC)	A	Percentage of audited MOCs that satisfied all aspects of the site's MOC procedure
	B	Percentage of audited changes that used the site's MOC procedure prior to making the change
	C	Percentage of start-ups following plant changes where no safety problems related to the changes were encountered during re-commissioning or start-up
Process Safety Training and Competency	A	Number of Individuals Who Completed a Planned Process Safety Metrics (PSM) Training Session On-time)/(Total Number of Individual PSM Training Sessions Planned) x 100%.
	B	Number of Individuals Who Successfully Completed a Planned PSM Training Session on the First Try)/(Total Number of Individual PSM Training Sessions with Completion Assessment Planned for that time period) x 100%
	C	Number of safety critical tasks observed where all steps of the relevant safe working procedure were not followed)/(Total number of safety critical tasks observed) x 100 %

Note 1 An organisation can select one or more options for each leading indicator if available

Therefore, there is a significant gap that needs to consider KPIs during all phases of a development's lifecycle, including the design phase, and this should identify design aspects that will shape the ability of a development to meet safety performance requirements in all subsequent phases, e.g. KPIs for meeting inherent safety in design. This is particularly important since the work done during the design phase helps establish the effectiveness of safety performance in subsequent lifecycle phases. There are other forms of measurement of safety performance. The Centre for Chemical Process Safety, established in 1985 by the American Institute of Chemical Engineers for the express purpose of assisting industry in avoiding or mitigating catastrophic chemical accidents, focuses on process-related incidents [217]. The KPIs for lagging indicators are similar to those described in Table 7 used by OGP, IADC and HSE. For leading safety performance indicators, the Centre for Chemical Process Safety uses the criteria set out in Table 9

In the context of lagging indicators, it attempts to distinguish between process and other incidents. For example, a fall resulting in a lost workday injury is not reportable simply because it occurred at a process unit. However, if the fall resulted from a chemical release, then the incident is reportable.

Step Change for Safety [218] defines a Leading Performance Indicator as, *"something that provides information that helps the user respond to changing circumstances, and take actions to achieve desired outcomes or avoid unwanted outcomes"*. It warns that leading performance indicators can be ineffective if the wrong areas are targeted, the actions proposed are not sufficiently demanding, they are used superficially to get good scores, and the subjectivity of the assessment produces [inappropriate] self-deception of performance.

The association between the type of indicators that an organisation finds effective was made by Dr. Alan Sefton when he was head of the Offshore Safety Division of the HSE [219]. During his keynote address at an IADC conference on Leading Performance Indicators, he observed that,

“...the design standards and safety factors a company adopt is a leading indicator of company values, and the quality and sophistication of indicators goes hand in hand with safety management systems and cultural developments”. Step Change for Safety proposes three levels of leading performance indicator:

- *“Level 1 - Compliance: The leading performance indicators populating this level will be associated with compliance, in other words ‘is the organisation implementing its management systems and complying with its requirements as stated in legislation?’*
- *Level 2 - Improvement: The leading performance indicators at this level will be associated with monitoring the effectiveness of the company’s management systems.*
- *Level 3 - Learning: At this level, continuous learning and improvement is the norm for all parts of the organisation”*.

It recommends that the characteristics of good indicators (which also apply to lagging indicators) are:

- a) “Objective and easy to measure and collect,*
- b) Relevant to the organisation or workgroup whose performance is being measured,*
- c) Immediate and reliable indications of the level of performance,*
- d) Cost efficient in terms of the equipment, personnel and additional technology required to gather the information, and*
- e) Understood and owned by the workgroup whose performance is being measured”*.

Step Change for Safety suggests that the following leading indicators listed in Table 10, satisfy the above criteria.

Table 10 Examples of Leading Performance Indicators

Level	Description	Leading Indicators
1	Compliance	% of applicable legislation addressed by Company procedures
		% statutory training completed
		% of Safety Management System that is compliant with current guidance (e.g. HS(G)65; BS 8800; OHSAS18001).
		Number of management safety visits completed against number planned
2	Improvement	Perceptions of management commitment to safety
		The extent to which plans and objectives have been set and achieved
		Number of suggestions for safety improvements
		Number of safety audits planned and completed
3	Learning	% of jobs with defined National Vocational Qualification ¹ (NVQ) requirements
		% of identified competency gaps addressed
		% of planned equipment tests meeting performance criteria, e.g. % of Emergency Shut Down (ESD) valves that close in required time
		% of jobs for which risk assessments are carried out

¹ NVQ is a 'competence-based' qualification achieved by learning practical, work-related tasks designed to help develop the skills and knowledge to do a job effectively. NVQs are based on national standards for various occupations. The standards say what a competent person in a job could be expected to do. As someone progresses through the course, their skills and knowledge are compared with these standards.

The literature does not explore, in detail, the implied and necessary link between lagging and leading performance indicators, or any mix between them. OH&S-MSs require a feedback mechanism such that, following an incident (e.g. lagging indicator) or non-compliance from an audit (e.g. leading indicator), the OH&S-MS is adjusted to prevent recurrence. For example, if leading indicators are effective, then the factors that could result in incidents should be systematically eliminated prior to an undesired event, and there should be a continuous and sustainable improvement in safety performance. Equally, incident investigation should identify both the immediate and root causes, and these should be fed into the process for developing leading indicators, achieving similar results. If this association is broken, then the potential synergy that one can offer the other no longer exists.

2.7.2 Association between major and minor accidents and incidents

There are many major hazards in the E&P industry. In the case of offshore operations the fatality rate from each area has been predicted by Mansfield, Poulter and Kletz [101], (Table 11), and this is dominated by hazards relating to hydrocarbon releases.

Table 11 Predicted Major Hazards Fatality Rate for Offshore Activities

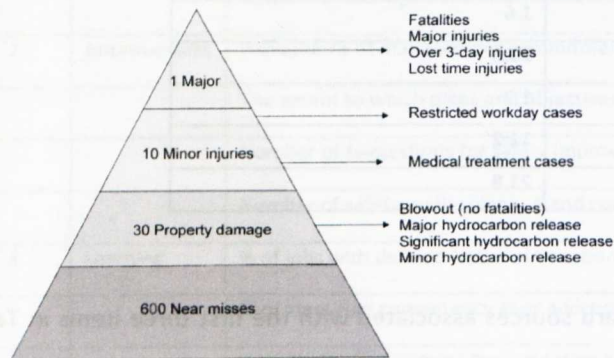
% Predicted Fatality Rate by Major Hazards – by Hazard Source	
Process	38.8
Blowout	2.0
Riser/Pipeline	1.6
Structural Mobile	23.0
Structural – Fixed Installation	1.7
Collision	11.2
Helicopters	21.8

Adding the hydrocarbon hazard sources associated with the first three items in Table 11, gives a percentage fatality rate due to hydrocarbon events of 42.4%, which is almost double that from any other single major hazard source.

This is not surprising given the inherent hazards relating to process safety in the oil and gas industry, such as pressure, temperature, and composition, in combination with relatively large inventories and the number of potential leak paths (e.g. valves, flanges, pumps, compressors, etc.) [220]. Process characteristics also change over time as reservoirs deplete, although ongoing development programmes, such as drilling new wells can increase original hazards. Hence, Process Safety is a particularly important indicator of safety performance for preventing major accidents when considered in relation to operational practices and preventative maintenance regimes, designed to ensure asset integrity. In terms of hydrocarbon releases there is a self-evident link between apparently minor incidents and those leading to explosions and fires such as at Piper Alpha [10] and Texas City [18]. It can also be argued that the theoretical and proportionate association between minor incidents and major accidents should provide an

organisation with the means to predict the potential for a major accident as there are likely to be considerably more minor incidents than major accidents. Equally importantly, recognition of such an association would give managers the information required to take a proactive approach, and therefore prevent injury and ill health, or further mitigate the consequences of failure. One of the more widely-established theories about the nature of workplace accidents relates to Total Loss Control (TLC) and the 'accident triangle', illustrated in Figure 22 [221] [222] [223, 224].

Figure 22 Bird and Germain's Accident Triangle



Note the descriptions outside the triangle, in Figure 22, are based on a personal interpretation of oil and gas industry incident classification

Early work in the development of accident triangle theory is described in '*Industrial Accident Prevention by Herbert William Heinrich*' [225]. One empirical finding from the first edition of his book (in 1931) became known as Heinrich's Law: that in a workplace, for every accident that causes a major injury, there are 29 accidents that cause minor injuries and 330 accidents that cause no injuries. Because many accidents share common root causes, addressing more commonplace accidents that cause no injuries can prevent accidents that cause injuries. Heinrich's classic work has been revised into the more recent book, '*Industrial accident prevention: a safety management approach*' [226]. The ratios between different types of incident are a fundamental principle in loss control but the numbers on which the original study ratios were based, were limited. Later studies carried out by Bird and Germain [227] involving some 1.75 million accidents from 297 co-operating organisations, resulted in a ratio of 1:10:30:600. The

analysis suggests that, preceding every major injury, there are likely to have been 10 minor injuries, which were preceded by 30 instances of property damage (including plant and equipment damage), and which were preceded by 600 near misses (often quoted as 'near hits' – typically an incident that did not result in injury or damage but had the potential to cause either or both) as shown in Figure 22. In another study, *'The Costs of Accidents at Work'* [4] investigations were carried out at a creamery, a construction site, a transport company, a hospital and an oil platform. The results are described as: over 3-day injury/minor injury/non-injury accident, with an associated ratio of 1:4:126.

The allocation of industry incidents is illustrated in Figure 22 to show how they might interface with Bird and Germain's triangle. It is important to note that, for example, blowouts (uncontrolled release of formation fluid from a well) are likely to cause significant asset damage, while hydrocarbon releases may not. Both blowouts and hydrocarbon releases have the potential for escalation as is evident from the incidents involving the GSF Adriatic IV Jack-Up (the rig was drilling a natural gas well when a gas blowout occurred during drilling operations. More than 150 workers on the jack-up and platform were evacuated with no casualties [228]), Piper Alpha [10], Texas City [18], Buncefield [21], and the Transocean blowout and sinking of the Deepwater Horizon rig in the Gulf of Mexico (GoM) [20]. However, if no injuries occur then they will not form part of OGP and IADC safety performance statistics (KPIs), since these are injury-based, yet the consequences are potentially huge in terms of:

- loss of revenue and recovery and liability costs;
- environmental impacts, particularly when onshore and where the public are affected;
- reputational impacts and the loss of confidence from stakeholders, including governments;
- economic impacts, both in the short-term and long-term, affecting the company(ies) involved and their viability; and

- individual impacts (both employees and the public) causing financial, physiological and psychological harm.

As discussed, the literature describes variations associated with these ratios. For example, in a study on quarries [229], a ratio of 1 major injury or illness to 7 minor injuries or illnesses and 189 non-injury accidents or illnesses was reported, but the principle remains the same: reducing the number of injury-free near-misses (near-hits) at the bottom of the triangle through proactive improvement in safety performance reduces the number of incidents in the upper sections of the triangle where people are hurt. This theory is supported by the practical experience from Norsk Hydro, where it was stated that they:

“focused on near-miss reporting offshore in the late 1980s where it was evident to see an inverse proportionality between the number of reported near-misses and the number of accidents. When line managers managed to get an increased focus on the importance of near-misses, and thus increased reporting and learning from them, the number of accidents fell. When the organisation relaxed on near-misses, the number of accidents increased”. [230]

It is evident from the published literature that there is consensus about the principles that underpin accident theory, although the ratios themselves vary according to the type and scale of study undertaken. However, it appears that the both OGP and IADC annual incident reporting statistics, for example, lack near-miss data (although OGP publishes accident triangles). The impact this has on the value of the statistical presentation and subsequent analysis is unclear in the Annual Reports.

In this context the UK HSE hydrocarbon release data [231] and SINTEF Blowout data [232] provide more reliable sources of information since, in the main, their reporting is based on statutory requirements, e.g. UK RIDDOR [214], whereas OGP and IADC data are entirely voluntary and from member organisations.

In terms of accident theory, failure to report instances of property damage and near-misses constitutes a significant omission as it effectively eliminates the opportunity to address their causes before the failures that contributed to these events collude with other factors resulting in a more serious outcome. For example, if the Bird and Germain accident ratios are applied to the OGP Safety performance indicators 2006 data [233], comprising 115 fatalities, theoretically there would have been 1150 minor injuries, 3450 classifications of Property Damage, and 69,000 near-misses. Consequently, the absence of over 70 000 events from the data is obviously a potentially serious loss of valuable information.

Another important feature of the hydrocarbon release database, in relation to accident causation theory, is that, assuming there was no injury following a release or property/asset damage, the event would be classified as a near-miss. Therefore, it may be treated less seriously than a minor lost time injury, although the near-miss might have a much higher potential for a major accident event (e.g. hydrocarbon release).

According to accident prevention theory, OGP, IADC and HSE, in isolation, do not provide comprehensive performance data. This may be due to the voluntary requirement for reporting, the use of reactive KPIs, and the absence of major accident data, at one end of the accident triangle, and property damage and near-misses at the other. Furthermore, given the lack of global agreement in major accident definition and the difficulty and uncertainty when using available accident databases, this problem is likely to be amplified for global property damage and near-miss reporting. However, as part of the effective implementation of an OH&S-MS, property damage and near-miss investigation, reporting and recording, should be happening at the organisational level. This information could then be fed into the process for global analysis. Since it does not appear in the global safety performance data, then perhaps it is not being [adequately] reported and recorded at the organisational level.

Irrespective of the challenges in collecting and collating large amounts of data for learning adequate lessons from the past, it follows that if industry performance is based on limited data then there is a greater chance that the underlying (root causes) factors that result in accidents, and in particular major accidents, will remain unknown (latent failures [234, 235]) and then major disasters will appear to occur 'randomly' as the conditions that would have preceded these events would not have been fully recognised, and therefore the industry would not have reacted in advance to prevent their occurrence.

Similarly, the extensive use of reactive (injurious) KPIs, are likely to preclude any significant warning of a more serious event. This was also one of the conclusions of the investigation into the causes of the three incidents that occurred at the BP Grangemouth Complex between 29th May 2000 and 10th June 2000 [236], involving a power distribution failure (29th May), medium pressure (MP) steam main rupture (7th June) and Fluidised Catalytic Cracker Unit (FCCU) fire (10th June), where each had the potential to cause fatal injury and environmental impact, although no serious injury occurred. The conclusion stated,

"Inadequate performance measurement and audit systems, poor root cause analysis of incidents, and incorrect assumptions about performance based on lost time accident frequencies (DAFWCF – days away from work case frequencies) and a lack of key performance indicators for loss of containment incidents meant that the company did not adequately measure the major accident hazard potential. Since the incidents, BP has worked in conjunction with the wider chemical industry and with the HSE to develop new Key Performance Indicators for process safety".

The majority of industry data collected by OGP and IADC, and some of the HSE data are reported on a voluntary basis, and since there is no statutory or mandatory obligation to report incident data, particularly in the case of non-members of OGP and IADC, it is less likely to be a comprehensive and accurate record of the industry's actual safety performance. This

limitation can only add to the vulnerability of the industry to incur incidents of all severities. This lack of published comparative data for all incident types, and therefore associated analysis, fails to produce an accurate indication of previous problems, which in turn creates a confusing picture of what improvements are needed, and is not conducive to cost-effective decision-making. However, it is possible that this may be happening within companies, although there is evidence from the UK's Royal Society for the Prevention of Accidents (RoSPA) that there are obstacles to reporting at this level [237]. For example, RoSPA believes that, in general, the reporting of incidents is not encouraged for the following reasons:

- *“employee fear of consequences;*
- *no investigation takes place (coupled with massive under-reporting to enforcing authorities);*
- *no clear procedures established for investigation (and/or no managerial involvement);*
- *no workforce involvement occurs (trades union safety representatives have a legal right to investigate accidents)”.*

2.8 Summary

It is evident that there are a number of factors, listed above, that can influence decision-making by management, and which have an impact on the ability to deliver OH&S objectives. The application and implementation of an OH&S-MS, and the weighting, partly driven by the safety culture, that an organisation applies is not prescribed. Furthermore, the ability of an organisation to achieve continuous and sustainable improvement in safety performance may be impeded, but not necessarily prevented, by the competing demands for resources, from a finite base, all of which can change over time. However, despite these potential constraints, many organisations, as demonstrated by the research that led to HSG 65, prove that some organisations, particularly during their operational phase, can achieve a successful safety performance. Consequently, there

is no firm evidence to suggest that an OH&S-MS does not provide the basic framework for an organisation to meet safety objectives, and achieve its safety-related goals.

In a largely non-prescriptive goal-setting regime, management have considerable flexibility in deciding risk tolerability and risk levels, but this should be supported by an independent, competent, and adequately-resourced regulator, to ensure that risk is not adversely compromised by, for example, financial and commercial pressures influencing decision-making.

The tools and techniques used in project and risk management are generally well-tried and tested. However, variability in the access to reliable and accurate data and the application of judgment can result in potentially large variations in the quality of assessments. The components of an OH&S-MS lack detail, and emphasis (e.g. the use of inherent safety in design), in the implementation of suitable and sufficient risk assessments during each of the project phases.

This is particularly important when highlighting the need to eliminate or minimise risks in design, the stage which offers the most cost-effective lifecycle solution.

The way in which, at a global level, the industry collects, collates, analyses and presents safety performance data, is unlikely to achieve either the rate of improvement, and a continuous and sustainable improvement, particularly in the context of major accident hazards, and this is generally confirmed by the case study accident investigation reports. Many of the accident databases are fee-based, and random interrogation would generally be uneconomical for smaller enterprises or researchers. Interrogation of available databases is difficult given the variety of definitions (e.g. major accidents or disasters?) and construction of search criteria within the databases, resulting in inconsistency of findings, and uncertainty in the validity and accuracy of the data. This problem would be amplified for less serious events due to the added volume of data.

3. CHALLENGES TO TRADITIONAL OH&S-MSs

3.1 Introduction

This section examines relatively recent theories and concepts that are intended to further explain and support continuous and sustainable improvements in safety. They are:

- Inherent safety;
- Normal accident theory;
- Resilient Engineering;
- High Reliability Organisations; and
- Human Factors

They are generally treated as mutually exclusive and there is no literature that considers the effective integration of all five, although this may have benefits or synergies that provide a greater chance that safety performance goals can be achieved, or that that they can be achieved more cost-effectively.

3.2 Inherent Safety

3.2.1 Introduction

Inherent safety (In this respect the term Inherent safety includes the concept of inherently safer design) is not a modern phenomenon and, historically, there have been various initiatives to safeguard personnel by reducing the risk from industrial processes, e.g. in 1867 Alfred Nobel invented dynamite by absorbing nitroglycerine on a carrier, greatly enhancing its stability [238, 239]. Dr. Trevor Kletz has been a more recent advocate of inherent safety when he initially presented the concept at the 1977 Annual Jubilee Lecture to the Society of Chemical Industry in Widnes, England. This was published in 1978, and in 1985 he published a paper '*Inherently Safer Plants*' [240] [241]. Inherently Safer Design (ISD) achieved greater prominence following disasters such as Mexico City 1984 (where there was a major fire and a series of catastrophic explosions at the government owned and operated PEMEX LPG Terminal at San Juan Ixhuatepec, Mexico City.

As a consequence of these events some 500 individuals were killed and the terminal destroyed) and Bhopal 1984 [242, 243]. Consequently, various bodies, such as government and regulatory authorities, Industry working groups which developed the INSIDE (INherent SHE Evaluation Tool designed to encourage greater application of the principles of inherent safety) project, and non-government organisations, took an interest in ISD [244-246] [247, 248] [249]. Tools are available to compare the relative safety of chemical plant, e.g. the Dow Fire & Explosion Index and the Dow Chemical Exposure Index [250], to apply the concept in accident investigation [251], while research into inherent safety and ISD has been reviewed in publications including; *'Inherently Safer Chemical Processes: A Lifecycle Approach'*, *'Inherently safer design: Present and future'*, *'Inherently safer design—its scope and future'* and *'How to make inherent safety practice a reality'* [252-255].

OGP suggests that an OH&S-MS may not be able to identify the hazards or risks relating to a major accident given the complexity of some failure scenarios. However, it could equally be argued that the failure is in designing a plant that is too complex and tightly-coupled (described in more detail in Normal Accident Theory later), and that those designs based on the principles of inherent safety would instead provide a greater opportunity to achieve a desired level of safety performance [256, 257]. The UK HSE supports this approach and states,

"adoption of the principles of inherently safer design is particularly important where the consequences of plant or system failure are high".

This is more important in those industries that experience disasters, i.e. rare but high severity events. The UK HSE therefore advocates ISD features, where these are possible, to reduce the reliance on engineered safety systems or operational procedures (lower order controls), to manage risks which are more susceptible to failure, and may require unnecessary exposure, and associated risks, to maintain safety systems. There is evidence that many of the failures that arise during the lifecycle of a project stem from poor design [258-264]. For example, it is quoted for the

accidents and incidents in the aircraft and nuclear industries, 51% and 46%, respectively, that these have a root cause in design. For the railway industry, quantitative analysis was not possible but poor design was a significant contributor to recent major rail accidents [260]. In the chemical and nuclear industries it is reported that about 20% to 50% of studied incidents and accidents have at least one root cause attributed to erroneous design. Although the number of design errors actually occurring during the design process is much higher, 80–95% of them are removed by thorough design reviews [261]. This naturally assumes that thorough design reviews are carried out effectively and at the right time, when sufficient information is available to make valid judgments, and to allow changes to be made without significant impact on cost schedule.

In this context the UK HSE also applies the concept of ‘defence in depth’, i.e. redundancy, diversity and segregation, the provision of multiple barriers and other good practices [101]. These are set out in the UK HSE’s safety assessment principles for nuclear facilities [265] which are seen to be fundamental to ensuring safety. The general principles of inherent safety are;

- *“first, to avoid the hazard and maintain safe conditions through inherent and, where appropriate, passive design features; and,*
- *secondly, to minimise the sensitivity of the plant to potential faults, as far as can be reasonably achieved, by ensuring the plant response to a fault is as near the top of a hierarchy, i.e. (i) produces no operational response or a move to a safer condition; (ii) passive or engineered safeguards, continuously available, make the plant safe; (iii) active engineered safeguards, brought into service in response to the fault, render the plant safe”.*

Consequently, the concept of inherently safer design refers to an approach to design in which hazards are ‘designed out’ or mitigated at source. Typically, the primary means of prevention are the use of appropriate standards for design and operation, the optimisation of the layout for safety, and the quality standards applied to design, construction and operation. The greatest

opportunities to reduce risks are during the initial hazard identification stage at the conceptual design phase, since once into detailed design there may be limited scope to apply hazard avoidance (as opposed to prevention) methods. Facilities designed on this basis can be described as intrinsically or inherently safer [266]. This suggests that the setting of appropriate OH&S objectives, and design-based KPIs, as a part of the OH&S-MS at the start of any development, i.e. the concept phase, or equivalent, must consider all lifecycle phases if the safety objectives for its lifetime have any genuine prospect of being achieved. Currently the inherent safety approach tends to mainly focus on the major hazard issues.

While this focus is about eliminating or mitigating the severity of incidents due to escalation and the domino effect and is a critical and essential element of OH&S, it does not adequately address the huge number of incidents and accidents that relate to single fatalities, the huge volume of lost time injuries, restricted work cases, medical treatment cases, first aid cases and the significant asset losses incurred regularly by the industry [267]. Therefore the application of inherent safety needs to have a much broader perspective, in particular, during the design phase, in that:

- it is cost-effective at this stage, when assessed over the development lifecycle;
- it eliminates the need to make design modifications during subsequent lifecycle phases, particularly during the operational phase when it potentially increases the risk to personnel and can incur significant costs due to loss of production and revenue; and
- it avoids the need to overcome design error through the application of appropriate competencies and experience and design review.

However, major obstacles to effective application of ISD might be:

- Design engineers in all disciplines are less familiar with ISD and therefore lack the necessary competencies to apply the concept effectively; and

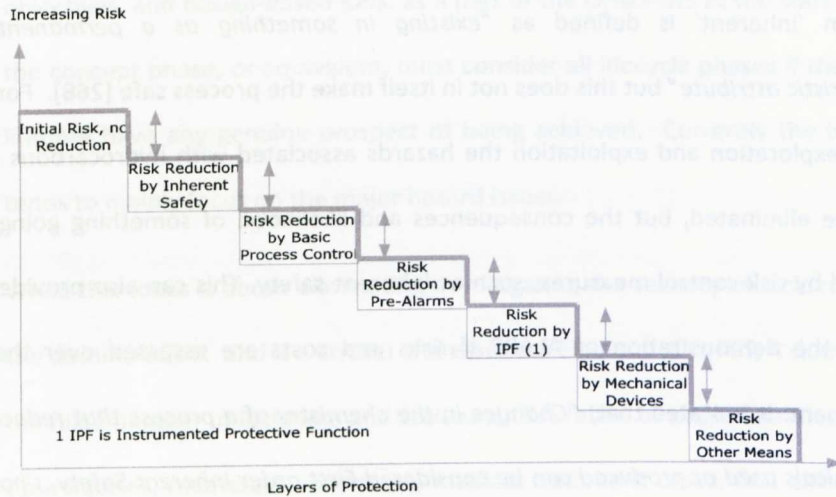
- Unless there is a top-down drive and commitment to apply ISD then Project Managers may be reluctant to prioritise its use, especially if it could compromise traditional project KPIs of cost and schedule

3.2.2 Concept of Inherent safety

The term 'inherent' is defined as *"existing in something as a permanent, essential, or characteristic attribute"* but this does not in itself make the process safe [268]. For example, in oil and gas exploration and exploitation the hazards associated with hydrocarbons under pressure cannot be eliminated, but the consequences and likelihood of something going wrong can be mitigated by risk control measures, such as inherent safety. This can also provide a more robust case for the demonstration of ALARP if risks and costs are assessed over the lifecycle of a development. It is stated that, *"Changes in the chemistry of a process that reduce the hazard of the chemicals used or produced can be considered First order Inherent Safety. Changes in process variables can be considered Second order Inherent Safety"* [239]. However, to achieve a risk(s) that is both tolerable and ALARP over the lifecycle of a development, a range of risk control strategies may need to be assessed. This includes concepts such as inherent safety but may be complemented by additional tools and techniques such as Layers of Protection Analysis (LOPA) [269]. LOPA is one of a number of complementary techniques developed in response to a requirement within the process industry to be able to assess the adequacy of the layers of protection provided for an activity [269], analogous to the UK HSE concept of 'defences in depth'. Initially this was driven by industry codes of practice or guidance and latterly by the development of international standards such as IEC61508 [270] and IEC61511 [271]. In a typical chemical process, various protection layers are in place to lower the frequency of undesired consequences.

This includes: the process design (including inherently safer concepts); the basic process control system; safety instrumented systems; passive devices (such as blast walls); active devices (such as relief valves); human intervention; etc. as illustrated in Figure 23.

Figure 23 Risk Reduction Hierarchy



However, a perennial discussion among decision makers is:

- how safe is safe enough?
- how many (and what type) of protection layers are needed? and
- what should each layer contribute in the overall risk reduction strategy? (particularly as some layers may be regarded as more robust than others).

LOPA is therefore designed to provide rational risk-based answers to these questions but often lacks valid and accurate source data, and therefore is, at best, semi-quantitative.

3.2.3 The Role of Inherently Safer Concepts in Process Risk Management

It is argued that inherent safety provides greater risk reduction at lower comparable costs than risks that are controlled by, for example, active protection or procedures, since these demand greater ongoing costs in terms of training personnel and maintenance [239].

Furthermore, the later the introduction of inherently safer systems during the lifecycle of a development, the more it is likely to cost, although inherent safety can be applied at any stage of the lifecycle [272-274]. Therefore the most cost-effective strategy would be to apply inherent safety during the early stages of a development. However, to fully comply with ALARP, previously managed risks and their risk control strategies would need to be continuously reviewed, as inherently safe techniques and technologies are superseded when new and novel concepts are developed in pursuit of more cost-effective operations. Moreover, techniques and technologies that were uneconomical may become attractive as screening criteria change towards inherent safety. Approaches to the design of inherently safer processes and plants have been grouped into four major strategies by the Institution of Chemical Engineers (IChemE), IPSG [275] and Kletz [276, 277]:

- *“Minimise. Use smaller quantities of hazardous substances (also called Intensification).*
- *Substitute. Replace a material with a less hazardous substance.*
- *Moderate. Use less hazardous conditions, a less hazardous form of a material, or facilities that minimize the impact of a release of hazardous material or energy (also called Attenuation and Limitation of Effects).*
- *Simplify. Design facilities which eliminate unnecessary complexity and make operating errors less likely, and which are forgiving of errors that are made (also called Error Tolerance)”.*

3.2.4 Inherently Safer Strategies

In the oil and gas industry there are inherent hazards, e.g. hydrocarbons under pressure. In terms of hazard management there are various classifications of ISD:

- *“First-order inherent safety involves eliminating hazards from the process altogether;*

- *Second-order inherent safety attempts to reduce the magnitude of a hazard, or make it extremely unlikely, perhaps nearly impossible, for an accident to occur; and*
- *Layers of protection” [278].*

First Order inherent safety, i.e. the elimination of the hazard, is not applicable in the main hydrocarbon processes in the oil and gas industry, although it may also be argued that if people are removed from this hazard, then while the hazard exists, the risk to people has been eliminated, and therefore it is inherently safe. However, this discussion might then extend beyond the safety domain to the environmental arena, where any risk of loss of containment may not directly affect people but could have increased risk for the environment, if there is no one available to quickly control the source of leakage.

The four major strategies of Minimise, Substitute, Moderate and Simplify apply in that it may be possible to have smaller inventories, use less hazardous substances for process management, develop unmanned installations (onshore and offshore) and simplify designs to make them less prone to, or to mitigate, failure or error. The literature also describes other safety strategies that are typically associated with hazard management and not always associated with inherent safety [279-281]. They are:

- *“Limitation of effects (consequence management/mitigation)*
- *Limiting escalation of knock-on effects*
- *Avoiding incorrect assembly*
- *Making status clear*
- *Instilling inherent robustness (e.g. resilient engineering)”.*

The INSIDE (INherent SHE In DEsign) project [247] was a European government/industry project established by the Commission of the European Community in August 1994. The goal of the INSIDE Project was to develop practical ways to encourage the use of inherent safety in process development and plant design. The result of this work has been a collection of tools and methods

known as the INSET Toolkit that was specifically designed for this purpose [282]. The toolkit is specific to inherent safety and is relevant for all phases of a project, including modifications, but it is not intended to be a substitute for the various safety engineering studies normally carried out in projects. However, there is recognition that, in the early phases of a project, it is beneficial to qualitatively estimate total lifecycle costs and risks for competing options, since the level of detail required for a quantitative assessment would generally be unavailable, in order to select the option for further development that provides ALARP. Cost benefit analysis (CBA) may be a useful tool to aid decision making in this context) [146].

3.2.5 Implementing Inherently Safer Design

In the UK the Health and Safety Executive publish criteria for assessing compliance with the law in individual cases, and the use of good practice, (within the UK HSE, good practice is the generic term for those standards for controlling risk which have been judged and recognised by the UK HSE as satisfying the law when applied to a particular case in an appropriate manner [283]). In this context reviews of design projects were carried out by three teams of UK HSE Offshore Safety Division (OSD) inspectors from a spread of topic backgrounds [284]. A cross-section of project and Operator Company staff were interviewed, ranging from a UK managing director to contractor discipline engineers. The findings were assessed against the key components of HSG(65) [32]. The Review stated that, *“In inspecting design and construction projects, the key indicator for effective corporate management is: Corporate commitment to continuous safety improvement and inherently safer design”*.

There are references to inherent safety in the 1999 Control of Major Accident Hazards (COMAH) Regulations [96]. This requires the consideration and documentation of inherently safer design alternatives during the initial design stage. Principles of hazard control, section 15 states that,

“Major accident hazards should be avoided or reduced at source through the application of the principles of inherent safety”, while section 16 states, *“Operators are required to take 'all*

measures necessary' to prevent major accidents and limit their consequences (COMAH Reg. 4). Operators should therefore demonstrate that they have looked at ways of avoiding the hazards or reducing them at source through the application of the principles of inherent safety. The preferred approach to further risk reduction, after the application of inherent safety principles, is through the application of a hierarchy of measures comprised of prevention and control of hazards, followed by mitigation of events".

3.2.6 Inherent Safety Review Objectives

The application of inherent safety is similar to other forms of risk management. For example, it is important to identify how it is incorporated into the existing OH&S-MS, when it will be applied and updated as the project progresses through the lifecycle, who will participate to ensure that the right type of competencies and experience are involved and, what is expected in terms of the deliverables for the project. Many safety engineering studies use guidewords and it is therefore relatively easy to ensure that the ranking of preferred risk reduction methods, including inherent safety, is intrinsic in the set of guidewords.

3.2.7 Inherently Safer Design Conflicts

The transfer of risk might result in conflict. For example, reducing plant inventories to mitigate loss of containment incidents might require increased frequencies of road tanker movement to transport product to and from the sites. In this case the onsite risk reduction is achieved by an offsite risk increase [280, 285]. Consequently, setting the boundaries for studies to demonstrate ALARP is crucial to ensure that all relevant risks are captured, although it is possible that the protocols in reporting safety studies may not make study boundaries transparent, and this could be significant for risk transfer.

3.2.8 Economics

Where inherent safety can effectively be applied, the resultant process may, for example, be simpler, and smaller. This has the advantage of reducing capital expenditure and often operating

costs, since there is less to maintain. It also has the potential to reduce error and therefore downtime caused by system disruptions. Conversely, traditional designs tend to rely more on lower order layers of protection that require significant intervention to meet production efficiencies, and this in turn increases the number of personnel needed to satisfy maintenance and operational demands. This also increases their exposure to the hazards present in the process and therefore the collective risks relevant to the site, e.g. individual risk per annum (IRPA), i.e. in the fatality estimation the consequences of each scenario are represented by the probability of death for an individual. The IRPA is the sum of the probability of death from all the scenarios. Commensurate with increased personnel are increases in welfare arrangements, training and other competency requirements [286]. If inherent safety is not implemented, it does not mean that those sites cannot achieve continuous and sustainable improvements in safety performance, but it is likely to be at a greater cost (when viewed over the lifecycle of a project) than a process that incorporates inherent safety during design [287]. This is especially true of a process where the operational phase can last for decades and be subject to significant changes, such as organisational and, in some cases, ownership, e.g. Texas City 2005 [18].

When comparing ISD solutions to other solutions, designers should include the total lifecycle cost of each alternative before reaching a decision. For example, Noronha, describes the use of deflagration pressure containment design in preference to using deflagration suppression or other means of explosion prevention, based on lifecycle cost and reliability considerations [286].

In many cases, formal tools for decision making can be useful, particularly if the hazards vary greatly in type of consequence or impact. Many of these tools may introduce additional rigour, consistency, and logic into the decision process, but are not technically oriented. For example, weighted scoring methods, such as Kepner-Tregoe Decision Analysis, use a structured methodology for gathering information and prioritising and evaluating it. The idea is not to find a perfect solution but rather the best possible choice.

The Analytical Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. Rather than prescribing a 'correct' decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem. Based on mathematics and psychology, it provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions [196].

Cost-benefit analysis (CBA) is often used in the oil and gas industry. It is an analysis of the cost effectiveness of different alternatives in order to see whether the benefits outweigh the costs, and therefore can be extremely useful when making an ALARP case. The standard approach to CBA in risk assessment involves converting risks to life into equivalent costs, i.e. to place a value on a fatality [188]. The approach is typically calculated as:

$$\text{Net benefit} = \text{reduction in risk factored accident costs} - \text{cost of measure.}$$

An alternative approach is to use Implied Cost of Averting a Fatality (ICAF). This is expressed as:

$$\text{ICAF} = \frac{\text{Net annual cost of measure}}{\text{Reduction in annual fatality rate}}$$

If the net benefit is positive, the measure is regarded as cost-effective. The calculation is usually expressed using net present values (NPVs).

3.2.9 Inherent Safety International Standards

A key internationally-recognised standard, ISO 17776 [148] requires that inherent safety is addressed as part of the risk control hierarchy. Section 3 of the standard states that, "*Risk-reduction measures should include those to prevent incidents (i.e. reduce the probability of occurrence), to control incidents (i.e. limit the extent and duration of a hazardous event) and to mitigate the effects (i.e. reduce the consequences). Preventive measures, such as using inherently safer designs, and ensuring asset integrity, should be emphasized wherever practicable*".

The standard describes the selection of measures to reduce the risk, which should consider:

- *“the technical feasibility of the risk-reducing measure;*
- *the contribution of the risk-reducing measure;*
- *the costs and risks associated with implementing the measure; and*
- *the degree of uncertainty associated with the risk, or the risk-reduction technique, including human factors”.*

The standard, in effect, applies the ‘as low as is reasonably practicable (ALARP)’ concept that requires a progressive reduction in risk until such time that the cost outweighs the benefits.

However, the general suitability and application of standards in the oil and gas industry may be extremely variable. For example, OGP has produced a *“Catalogue of International Standards used in the Oil and Gas Industry”* [288]. The objective of the catalogue is to make users aware of the International Standards available, thereby enabling procurement costs of materials and equipment to be more efficient. This catalogue does not include regional or national standards developed by a recognised Standards Development Organisation (SDO), such as the British Standards Institute or the American Petroleum Institute, although it recognises that they may also be applied globally. Consequently, the catalogue is simply a limited listing of joint ISO/IEC Standards and standalone ISO and IEC standards. However, OGP, in their publication, *“Value of Standards”*, state that, *“Standards are the tools we use to organise our technical world. They underpin expectations that the platforms, systems and equipment will be safe, reliable and fit-for-purpose”*. However, the catalogue itself offers no value as a means of identifying and benchmarking good, or best practice, and therefore has limited use.

3.3 Normal Accidents

3.3.1 Introduction

Current accident theories relating to resilient engineering and high reliability organisations, both discussed later, make reference to the work carried out by Charles Perrow [289].

The work was inspired by the increase in high risk technologies and the commensurate need to manage them safely. The hypothesis is that no matter how effective conventional safety devices are, there is a form of incident that is inevitable. For major accident hazard operations the consequences of this analysis, if valid, have huge safety implications, i.e. the acceptance that there is nothing that can be done to prevent a major accident. The hypothesis revolves around the complexity of plants, which makes it virtually impossible to predict all the possible interactions in a way that ensures no single, or combination, of undesired events can cause immediate, or through escalation, major accidents. It argues that systems are often 'tightly-coupled' (as opposed to loosely-coupled) in that once a reaction has started it may happen so fast that no form of intervention will stop it. The author states, *"If interactive (linear and complex – discussed below) complexity and tight coupling – system characteristics, Table 12 – inevitably will produce an accident, I believe we are justified in calling it a normal accident, or a system accident. The odd term normal accident is meant to signal that, given the system characteristics, multiple and unexpected interactions of failures are inevitable. This is an expression of an integral characteristic of the system, not a statement of frequency."*

The main characteristics of tight and loose coupling can be illustrated as follows:

- Tightly-coupled systems have more time-dependent processes; they cannot wait, or be on standby until attended to. In loosely-coupled systems, delays are possible, processes can remain in standby mode and designs can allow substitution, etc.;
- The sequences, including design, in tightly-coupled systems are constant, such as in nuclear or chemical plants, whereas in other industries assembly of products or processes may be taken out of sequence; and
- Tightly-coupled systems have little slack, and quantities must be precise, while loosely-coupled systems can accommodate waste without great cost to the system.

Table 12 Key features of the interactivity of linear and complex systems

Complex Systems	Linear Systems
Tight spacing of equipment	Equipment spread out
Proximate production steps	Segregated production steps
Many common-mode connections of components not in production sequence	Common mode connections limited to power supply and environment
Isolation of failed components	Easy isolation of failed components
Personnel specialisation limits awareness of interdependencies	Less personnel specialization
Limited substitution of supplies and materials	Extensive substitution of supplies and materials
Unfamiliar or unintended feedback loops	Few unfamiliar or unintended feedback loops
Many control parameters with potential interactions	Few control parameters, direct and segregated
Indirect or inferential information sources	Direct, online information sources
Limited understanding of some processes	Extensive understanding of all processes

Perrow discusses the systems' prone to system accidents and develops the concepts of linear and complex interactions. Linear interactions are considered relatively simple and comprehensible although they may have limited complex interactions. These are dominant in most systems, whereas complex interactions are those where system components can interact with one or more other components outside the normal production sequence, either by design or by accident.

Paradoxically, Perrow argues that complexity is best since it is more efficient than linear systems, e.g. smaller footprint for offshore installations, therefore less cost for the same process, but, potentially, at the expense of safety performance. The purpose of defining systems in this way is to help understand their failure potential and therefore the controls, through design and/or operation, needed to adequately manage the associated risks. However, Perrow's analysis assumes that people are exposed to risk. Therefore, if people are removed from the hazard(s) then the effect of failure only relates to asset (financial) losses, and environmental and reputational effects.

There are further various ramifications connected with this theory. For example, it is assumed that about 60 – 80% of all incidents can be attributed to human error. It is argued that system behaviour cannot be fully understood by operators and therefore the human response to many events can be regarded as reasonable, even if subsequent investigation indicates that it may have been flawed. Furthermore, minor incidents can lead to major accidents but given the system complexity and tight coupling the significance of these events may not be transparent. The role of the organisation is also recognised as an important factor in incident causation and prevention, where there is often a conflict between centralisation and decentralisation, since both approaches can produce positive as well as negative results. However, a crucial failure of many organisations is in their inability to identify, and correctly react to, warning signals. Consequently, there is an operational naivety about the level of risk within the organisation. Potential fixes for normal accidents are therefore focused on organisations.

3.3.2 Three Mile Island

Perrow evaluated the accident at the Three Mile Island Unit 2 nuclear plant near Harrisburg, Pennsylvania, on 28 March 1979 that resulted in the release of moderate amounts of radioactive gases and radioactive iodine into the environment. This was the most serious in U.S. commercial nuclear power plant operating history, even though it led to no deaths or injuries to plant workers or members of the nearby community. Furthermore the US Nuclear Regulatory Commission (NRC) determined that public health and environmental assessments had been subsequently carried out by several respected organisations that showed the actual release had negligible effects [290]. However, it brought about major changes involving emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. It also caused the U.S. Nuclear Regulatory Commission (NRC) to tighten and heighten its regulatory oversight. A similar contributory factor of regulatory oversight was identified by the Deepwater Horizon investigation, some 31 years post-Three Mile Island, at the Piper Alpha Inquiry some 9 years post-Three Mile Island, and Texas City, 26 years post-Three

Mile Island. Resultant changes in the nuclear power industry and at the NRC had the effect of enhancing safety. Perrow argues that while the nuclear industry suggests it has 500 'reactor' years of operating experience; this does not in itself justify whether this is adequate or whether this experience is valid, given the various generations of nuclear plant design and operation. Plants are also getting bigger but scaling up plant size does not necessarily produce comparable and consistent risks and risk profiles. Consequently, he proposes that we have not had more serious nuclear accidents because plants have not had the time to reveal their full potential for danger. In other words, unidentified or incorrectly identified risks may not be corrected and may remain dormant (latent) for years until circumstances coalesce to result in an incident. A NRC review of operating plants in 1980, as a result of berating criticism from the Kemeny Commission, revealed that little had changed [presumably since Three Mile Island] and identified below-average facilities [291]. In fact, the wide-ranging failures identified by Kemeny are broadly similar to those described in the BP Texas City (2005) investigation. It is also noteworthy that most of the failures relate to lower order control systems. Therefore, it reinforces the need to consider higher order controls to reduce the likelihood of these types of incidents happening.

3.3.3 Petrochemical plants

Perrow identifies petrochemical plants as processes that provide some good examples of system accidents since they are regarded as being tightly-coupled together with complex (interactive) systems. They have relatively mature technologies, and established management systems but continue to incur accidents, which suggests there is an intrinsic problem with the processes employed. Perrow's report was written well before Deepwater Horizon. European incidents were analysed since they are seen to be more open than comparable U.S. investigations. Generally, low incident rates do not necessarily indicate safe operations. Perrow suggests that this is because, in the main, worker exposure to the worksite is relatively low and often in [protected] control buildings.

Various accidents were reviewed by Perrow in support of his hypothesis. For example, the Texas City disaster in 1947 started in a ship carrying fertiliser [292] where an initial explosion on the ship escalated to nearby facilities and the end result was that about one third of the city was burnt down, 561 people were killed and over 3000 injured. The cost of the damage was over \$100 million. One feature of this accident was that there had been extensive experience with the process, although following the accident changes were made to the design, firefighting and recovery systems to prevent recurrence, and limit their impact. At Flixborough (UK) on 1st June 1974 human error was identified as a significant contributory factor; Perrow believes that incompetence and negligence should be assumed in this type of operation as well as organisational ineptitude, as this is the 'normal' state of organisations. There were many warning signals that were ignored and since the process was tightly-coupled with complex systems, there were various latent failures that could only be addressed by the proper and timely resolution of warning signals. Perrow suggests that petrochemical plant fires and explosions are increasing in number, although this may be due to an increase in the number of plants rather than frequency. However, Perrow believes these are less safe because of factors such as arbitrage and downsizing. Based on information obtained from Swiss Re, a reinsurance firm specialising in petrochemical industries, risk is increasingly being transferred into the public domain, minimising the consequences to those that take the risks to increase profits.

Perrow states, *"The shift is from expending resources on inspection of the huge properties the firm reinsures (by forming a syndicate of insurers), to increasing the resources expended upon money management, or arbitrage. The number of inspectors has declined substantially, while the finance staff has increased substantially. Because the profit from arbitraging the spread between the currency of dozens of countries where they reinsure and collect premiums, is so great in total, it pays to insure more properties to obtain the premiums. Marginally safe properties become profitable, even though they will have more losses than the insurer must cover. The fewer the inspectors, the more marginally safe properties that will be insured"*.

This spreads the costs of fires and explosions while the profits to the insurers increase. Production pressures play another important part in normal accidents, particularly in combination with downsizing, and it is estimated that the increased profits from reductions in labour and safety costs may be more than enough to offset any wider costs associated with downsizing the workforce.

3.3.4 Normal Accident Theory and High Reliability Theory

It is suggested that the difference between Normal Accident Theory (NAT) and High Reliability Theory (HRT) is that HRT assumes that if we try harder, we can achieve our [safety] goals, irrespective of system complexity and tight coupling. However, NAT states that no matter how hard organisations try to achieve safety goals, there are intrinsic [latent] failures in systems because they are complex and tightly-coupled and therefore failures (incidents or accidents, minor or major) will occur at some point in time. In fact, all that can be done is either abandon them, or design them in such a way as to reduce the impact of a failure when it occurs.

Perrow examines the question, 'what is to be done'? He proposes three categories to resolve the problem of industries with tightly-coupled and complex systems:

- *"Systems that are 'hopeless' should be abandoned when the risks outweigh the benefits, e.g. nuclear weapons and nuclear power;*
- *Systems that we are either unlikely to be able to do without, but which could be made less risky with considerable effort, or where the expected benefits are so substantial that some risks should be run, but not as many as we are now running, should be kept; and*
- *Systems which, while hardly self-correcting in all respects, are self-correcting to some degree and could be further improved with quite modest efforts, should be kept".*

Perrow recognises that his analysis of the above categories could be wrong:

- *"If the science of risk assessment currently practiced is incorrect, i.e. the risk perception underpinning this theory is incorrect;*
- *If they are contrary to public opinion and values; and*
- *If there is a way to run these industries safely".*

This results in four tasks:

- *"To examine the concept and application of risk assessment, since it allows risks that are both unacceptable and incorrectly evaluated;*
- *To examine the field of decision-making, since it argues that the public is poorly equipped to play a role in decisions on risk;*
- *To examine organisational dilemmas in high risk systems; and*
- *To show how the analysis of the first three, together with the analysis of tightly-coupled and complex system industries produces suitable risk reductions [to tolerable] levels".*

3.4 Resilience engineering (RE)

3.4.1 Introduction

Resilience engineering is a paradigm for safety management that focuses on how people deal with complexity, under pressure, to achieve performance requirements. It accepts safety as a core value and therefore requires organisations to provide a level of investment that ensures they remain within a suitable range of stability by predicting departures from safe limits of operation. This also ensures that the organisation, as a minimum, prevents any adverse deterioration of safety performance and also provides the resources for continuous, and sustainable, improvements in performance. However, there is no universal agreement on the principles that underpin RE, nor is there any consistent use of RE terminology.

In RE, the challenge is to address complex and unstable systems (e.g. organisations) in order to develop strategies that are robust enough to accommodate variation. RE has been mostly studied in the context of complex systems of high risk, such as in the aviation, petrochemical and nuclear power industries [294].

Erik Hollnagel, a specialist in the field of resilience engineering, states that, *“Safety is the sum of accidents that did not occur. Whilst accident research has focused on accidents that occurred and tried to understand why, safety research should focus on the accidents that did not occur and try to understand why [294]”*.

In this context it is argued that a system is safe if it is impervious to adverse upsets from a stable state, and if the mechanisms for failure and therefore the ability to effectively apply timely and suitable risk management techniques, an essential ingredient for success, are understood. However, RE suggests that given the complexity and dynamic nature of many organisations and their processes, and external influences on their activities, linear accident models, e.g. Swiss Cheese/Domino model [234, 235, 295], cannot explain fully the many variables that contribute to an accident. RE argues that in normal conditions many accidents are prevented by people who are sufficiently flexible and adaptable to accommodate change, despite deficiencies in the management systems, which that might, for example, lag behind operational transformations. However, reliance on human interventions is also a cause of failures, e.g. a view that sees human fallibility as the consequence of wayward psychological processes such as forgetfulness, inattention, poor motivation and the like [296]. Since resilience assumes that failures will occur and that there is a need to be able to withstand harmful conditions and situations, the concept applies a more systemic approach. This is to ensure that an organisation can react with a level of expediency so that a state of dynamic instability, irrespective of the speed at which this occurs, is constrained and returned to a state of dynamic stability before any serious adverse outcomes occur.

To achieve this, RE monitors the application of the model that drives safety performance, e.g. the OH&S-MS, and measures performance against demands and continually adjusts the model to meet changing conditions. This includes monitoring decision-making in order to determine if the risks proposed or being taken are within prescribed safety boundaries, although defining these boundaries is difficult, especially if the boundaries are changing. This requires an understanding of how the system adapts and, equally, what changes are likely, such as:

- Buffering capacity: changes that can be absorbed without any significant change in the system;
- Flexibility versus stiffness: the system's ability to change in response to perturbations;
- Margin: how close the system is operating to performance boundaries, e.g. risk tolerability criteria;
- Tolerance: how a system reacts when close to a boundary
- Cross-organisational relationships: for example, Downward Resilience considers how to manage goal conflicts whereas Upward Resilience assesses how individuals/groups respond to safety strategies, such as their level of compliance or non-compliance.

While this is generally consistent with OH&S-MSs, it does not fully explain what criteria could be applied and how performance could be measured to ensure that the response needed to prevent incidents, when moving towards an unstable condition, could be fast and timely enough to revert to a state of stability before any adverse outcome occurs.

For example, the National Aeronautics and Space Administration (NASA) applied a policy of 'faster, cheaper, better' (FCB) that led to a number of accidents and an investigation report concluded that while NASA had a history of successfully carrying out some of the most complex and challenging engineering tasks, it was being asked to sustain this level of success whilst

continually cutting costs, personnel, and development time, and that these demands stressed the system to the limit due to:

- *“insufficient time to reflect on unintended consequences of day-to-day decisions,*
- *insufficient time and workforce available to provide the level of checks and balances,*
- *breakdowns in inter-group communications, and*
- *too much emphasis on cost and schedule reduction [297]”.*

The Report diagnosed the situation as being too ‘brittle’ and eroding of resilience. The findings of the Columbia Accident Investigation Report, (a disaster that occurred on February 1, 2003, when, shortly before it was scheduled to conclude its 28th mission, STS-107, the Space Shuttle Columbia disintegrated over Texas and Louisiana during re-entry into the Earth's atmosphere, resulting in the death of all seven crew members [298]) suggested that a ‘silver bullet’ strategy, the advancement of multiple goals that do not conflict with each other, is a mirage. Instead, the report recommended that new mechanisms were needed to balance the inherent tensions between the various goals within a project. Similarly, in Resilience Engineering, it is proposed that these tensions often cause increased complexity especially in conjunction with the pace of change and coupled with other influences, which inevitably lead to failure unless reconciled.

Systems need to be resilient against various threats [299]. These are categorised as regular threats that normally only require a standard response; the irregular threat that is considered extremely unlikely to occur but may have major consequences, and finally the unexampled event which is not considered foreseeable and therefore with no paradigm or prepared response. Resilience is the way in which the management system copes with both predictable and unpredictable undesirable events.

This gives rise to themes that embody the concept of resilience [300], as illustrated below:

- Being better at predicting the next accident, by being more sensitive to the pressures of normal work by normal people in normal organisations, although defining 'normal' is contentious unless perhaps, 'normal' relates to a dynamic environment undergoing constant change;
- Identifying drifts into failure modes, before failures occur, particularly where there are tensions within the system due, for example, to incompatible goals. However, detecting drift and taking the right action at the right time with the right people at the right place, etc. is also fraught with difficulty ;
- Charting the difference between what is actually being practised (what is actually happening) and theory (what senior managers would like to be happening) to ensure that risks and their controls can be calibrated as necessary; and
- Maintaining the safety profile even if risks appear to be well-controlled, in a relative stable environment.

3.4.2 Assessing resilience

Typical factors that contribute to a lack of resilience in organisations [301] include:

- [Safety] Defences erode under production pressure. This can include structural integrity, process containment, ignition control, protection systems (e.g. fire), detection systems (e.g. fire and gas), shutdown systems, and emergency response and lifesaving systems;
- The fact that past good performance is taken as a reason for future confidence about risk control;
- The fact that fragmented problem-solving clouds the big picture – mindfulness, discussed in the section on High Reliability Organisations, is not based on a shared risk picture;

- The failure to revise risk assessments appropriately as circumstances change or new relevant evidence becomes available;
- Breakdown at boundaries (e.g. breakdown at the internal or external boundary impedes communication and coordination);
- The organisation's lack of ability to respond flexibly and rapidly to changing demands;
- A lack of commitment to safety, in relation to competing goals; and
- The fact that safety is not inherent in the system.

There are also many potential conflicts, or tensions, within organisations, which are extremely difficult to reconcile [302]. For example:

- Formal procedures that, over time, capture lessons learnt that are often voluminous and difficult to apply in comparison with slim procedures that are easy to apply but may lack relevant content, e.g., corporate memory;
- Centralisation to achieve consistency and continuity, especially in multinational organisations where personnel often transfer, 'v' decentralisation and local autonomy; and
- Maintaining the *status quo* for stability 'v' the need to change to meet future challenges;
- Using tried and tested techniques and technologies 'v' developing new innovative systems and processes.

These factors are recurring themes in terms of adaptation and change but for an organisation to be resilient it has to be able to absorb, adapt and adjust to survive, although there is a lack of empirical evidence that unambiguously identifies exactly how this can be achieved.

3.4.3 Resilience and KPIs

RE prescribes a proactive approach to the use of KPIs [303], [102]. It considers that OH&S-MSs can deteriorate over time or become obsolete as a consequence of changes, and that continuous performance measurement is essential for successful OH&S Management. A particular type of measurement, which is considered important in RE, is auditing, since it is proactive identifying gaps between current and desired performance, and therefore helping to define corrective action before an incident occurs. RE also attempts to learn from normal working conditions, rather than from incidents, and subsequent incident investigations. However, in many respects these may already be covered by current OH&S-MS models in that tools such as Job Safety/Hazard Analysis [304] or Task Risk Assessment [305] are used in a proactive way, and auditing and review has been an essential component of an OH&S-MS since its inception [32]. The primary difference between them is that traditional OH&S-MSs tend to emphasise the reactive approach whereas RE focuses on proactive methods. While OH&S-MSs already prescribe the use of both reactive and proactive KPIs it is a matter for the industry to decide where and how to apply KPIs to achieve performance requirements.

3.4.4 Safety Resilience In UK offshore Oil and Gas Operations

Asset Integrity

Between 2000 and 2004 the UK HSE ran an initiative, Key Programme 1 (KP1) (not to be confused with Key Performance Indicator (KPI)) aimed at reducing hydrocarbon releases.

While this subsequently reduced the number of major and significant releases, it did not help to improve the number of minor releases, and minor releases can quickly escalate to major releases. Therefore, the HSE became concerned about the general decline in asset integrity and introduced Key Programme 3 (KP3) [306] to improve asset integrity. This was scheduled to run between 2004 and 2007. Key Programme 2 [KP2] started in 2003, and focused on unacceptable accident statistics from deck and drilling operations offshore, while KP 4 covers HSE's concerns about ageing and life extension inspection programmes (2010 – 2013).

The findings demonstrated a significant lack of resilience (given that many of the systems were originally in better shape than those found during the inspections).

3.4.5 Key Themes in RE

The seven characteristics present in highly resilient organisations are:

- Top-level [safety] commitment;
- A 'Just Culture' that encourages the reporting of issues and allows for human error but does not accept negligent behaviours;
- A learning culture where there is no denial of adverse events but where these are seen as positive lessons that have the potential to produce improvement;
- Awareness, in that personnel know what is actually happening (as opposed to what they are they led to believe is happening) and therefore they are aware of the current state of defences;
- Preparedness, not just in terms of the planning process but being ahead of problems so that corrective actions are taken before a problem emerges;
- Flexibility to adapt effectively, and in a timely manner, to changing conditions, irrespective of their complexity; and
- Opacity, so that the organisation understands the boundaries within which it needs to operate, can accurately and reliably measure moves towards these boundaries, and make corrections to avoid degrading defences such that it operates outside these limits [61].

3.5 High Reliability Organisations

One way of preventing accidents is to study organisations that do not have significant, or major, accidents. These are called High Reliability Organisations (HROs), Table 13. However, Hopkins [307] argues that the term HRO is not well defined and that this impairs the ability to identify whether an organisation can be labelled as an HRO [314]. In general, incident performance is not

a good indicator since there are many variables that can influence performance, such as under-reporting. However, this is overcome by identifying those organisations that exhibit a collective state of 'mindfulness'. *"The processes of mindfulness is intended to suppress tendencies toward inertia , i.e. mindfulness is as much about the quality of attention as it is about the conservation of attention. It is as much about what people do with what they notice as it is about the activity of noticing itself"* [308].

Table 13 Key Concepts of HROs

Key Concept	Sub Heading	Description
Respectful interaction	Trust	Respect others and be willing to base beliefs and actions on them
	Honesty	Report honestly so that others may develop valid beliefs
	Self-respect	Respect our own perceptions and beliefs without devaluing them
An informed culture	Just Culture	Encourage free exchange of information and allow for human error but not negligent behavior
	Reporting Culture	Remove fear from reporting, Have we learnt lessons and communicated them?
	Learning Culture	Learning is continuous
	Flexible Culture	Rules cannot be so complete that they cover every eventuality.

Hopkins suggests that HROs have very successful reporting regimes, driven by a reporting culture, given that:

- *"Reporting is audited;*
- *Personnel are told, in considerable detail, about what needs reporting;*
- *Incidents may be reported by 3rd Parties;*
- *Disciplinary action may be taken if personnel fail to report; and*
- *There is no 'dobbing on a mate' (e.g. informing on someone, or volunteering someone for an unwelcome task) particularly when there are no personal connections [309]".*

HROs are typically major accident hazard organisations, e.g. nuclear, aviation and petrochemical and therefore they do not have the luxury to learn by trial and error. Consequently another feature is that they are often subject to independent scrutiny from external regulatory bodies [310]. As with many other organisations there is often a potential conflict between safety and cost.

Air Services Australia, a government-owned entity, is considered to be an HRO [311]. To achieve this status a functional group was established that provided support across the whole organisation, leaving the business to focus on core activities, e.g. making a profit. Hopkins notes that many large organisations that are structured with independent profit centres, with little central control, have been implicated in numerous major accidents [312]

It is suggested that today's organisations are characterised by 'raplex' - rapidly evolving and complex, and that for organisations to survive they have to be capable of managing raplex [313] similar to NASA's experience of 'faster, cheaper, better', [314]. From an efficiency perspective an organisation needs to be tightly-coupled or integrated in a way that ensures it acts as one rather than the fragmented behaviours of many. In theory, this minimises costs since there is less waste. However, HRO theory suggests that most organisations operate at a suboptimal level because they are loosely-coupled.

High Reliability Organisations have a history of very safe operations, although many act in high-risk industries (e.g. aircraft carriers [315] and the nuclear industry [316]) and demonstrate a high combination of reliability, flexibility, effectiveness and efficiency [317].

Processes in HROs focus on failure rather than success, and while HROs are not error-free, errors that occur are not disabling [318] and reliability is the primary objective for HROs [316, 319]. Consequently, there are similarities with the concepts underpinning RE.

HROs are reliable because they have a state of 'mindfulness' which is less about decision-making and accident prevention and more about empowerment. HROs possess five qualities (Appendix A) enabling them to reach their state of mindfulness and achieve a balance between tight and loose-coupling, thereby maximising efficiency and reliability by continuously maintaining sensitivity to operations.

3.6 Human Factors

As some of the oil and gas industry has tried to improve asset integrity through the introduction of hardware solutions such as safety critical elements, performance standards and verification, it has also attempted to address human factors. The UK HSE published a document, '*Reducing error and influencing behaviour*', to help understand their approach to human factors [320]. It gives a simple introduction to generic industry guidance on human factors, in which it states:

"Human factors refer to environmental, organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety"

This definition includes interrelated aspects that must be considered: the job, the individual and the organisation. The publication states, *"human factors are concerned with what people are being asked to do (the task and its characteristics), who is doing it (the individual and their competence) and where they are working (the environment and the organisation and its attributes), all of which are influenced by the wider societal concern, both local and national. Human factor interventions will not be effective if they consider these aspects in isolation"*.

It is argued that human failures are not random but that there are patterns, and therefore understanding these patterns can help prevent error. Furthermore, different failure types have different causes and require different remedies.

The UK HSE publication, '*Reducing error and influencing behaviour*' indicates there are different types of human failure (unsafe acts) that could result in a major accident. They are:

- Unintentional errors such as; errors (slips/lapses) and mistakes; and
- Intentional errors, i.e. violations. Violations can be further categorised as routine, exceptional, situational and acts of sabotage

The probability of human failure is determined by 'performing-influencing' factors, including distraction, time pressure, workload, morale, noise levels and communication systems. Therefore it is argued that human error and rule-breaking is predictable and can be managed. However, common pitfalls in managing people and their performance include:

- *"Treating operators as if they are superhuman, able to intervene heroically in emergencies*
- *Providing precise probabilities of human failure (usually indicating very low chance of failure) without documenting assumptions/data sources;*
- *Assuming that an operator will always be present, detect a problem and immediately take appropriate action;*
- *Assuming that people will always follow procedures;*
- *Stating that operators are well-trained, when it is not clear how the training provided relates to major accident hazard prevention or control, and without understanding that training will not affect the occurrence of slips/lapses or violations, only mistakes;*
- *Stating that operators are highly motivated and thus not prone to unintentional failures or deliberate violations;*
- *Ignoring the human component completely, failing to discuss human performance at all in risk assessments, leading to the impression that the site is unmanned;*
- *Inappropriate application of techniques, such as detailing every task on site and therefore losing sight of targeting resources where they will be most effective; and*
- *Producing grand motherhood statements that human error is completely managed (without stating exactly how)".*

A Human Factors Investigation Tool (HFIT) has been developed to help improve the investigation and contribution of human factors in the causes of accidents [321]. The tool collects four types of human factors information:

- the action errors occurring immediately prior to the incident,
- error recovery mechanisms, in the case of near-misses,
- the thought processes which led to the action error; and
- the underlying causes.

Various explanations for human error have been published in recent years comprising lapses, mistakes and violations, and these can occur at any time during the lifecycle, e.g. design, construction, fabrication, and operation and maintenance [295, 322]. The OH&S-MS is intended to provide the framework that helps prevent or mitigate the potential impacts from human intervention, e.g. providing personnel with suitable competencies. While the OH&S-MS framework, arguably, contains the necessary components to secure sustainable improvements in safety performance, including the provision of adequate supervision and inspection, the relatively constant changes within oil and gas organisations may cause a differential between the ability to apply the OH&S-MS effectively and the need for continuity of operations. Furthermore, as experienced personnel leave, or transfer within an organisation, there may be a loss of 'corporate memory' that accompanies these personnel. Unless, for example, the procedures adequately capture this experience, and are written and managed to ensure effective implementation, then the historical experience acquired by personnel, i.e. lessons learnt, will be lost to the organisation. Obviously, the risk is that errors will be repeated. These phenomena may be more relevant to project teams given their temporary and transient structure, with often the lack of corporate experience.

It is suggested that it is necessary to integrate human factors into design, particularly for high hazard industries, in order to bridge the gap between designers and end-users. Without this

integration a facility may have operability problems and, consequently adverse impacts on safety performance [323].

Inherently safer techniques and technologies are often designed to tolerate human error, especially as in various sources of the literature people are considered to be primarily responsible for accidents.

In the context of human factors the 'process' includes more than the equipment and the chemistry. It includes the systems of training, supervision, and the provision of tools to the people who operate and maintain the plant, including the design of operating and maintenance procedures and other management systems.

Unfortunately many designs fail to adequately address and implement inherent safety, and therefore rely on lower order safety systems, such as procedural controls. For projects, often the easy and most cost-effective option, in the short-term, is to design a process that targets lower CAPEX. This may translate, for example, to reduced investment in higher reliability plant and equipment, which congruently requires greater maintenance and process interventions during the operational phase. This has the effect of increased personnel exposure to potentially hazardous conditions and a greater potential for human error. Factors that can contribute to procedural error include:

- obsolescence,
- inaccuracy, and
- unavailability

Proper design of procedures requires consideration of the following [324]:

- Completeness and accuracy: Does the procedure have enough information for the user to perform the task safely and correctly?

- **Appropriate level of detail:** Has the level of detail considered the experience and capabilities of the users, their training and their responsibilities?
- **Conciseness:** Conciseness demands eliminating detail and language that does not contribute to work performance, safety, or quality. Conciseness also means including only 'need-to-know' and omitting 'nice-to-know' information.
- **Consistent presentation:** This element ensures that the procedure is readily comprehensible.

Given the dynamics of people movements, particularly within large organisations, maintaining these aspects for all relevant people, at all times, presents a significant challenge, and is probably unrealistic.

The Energy Institute, in the UK, in collaboration with Det Norsk Veritas (DnV, a classification society in Norway with the objective of safeguarding life, property and the environment) has published guidance to help non-specialists manage human factor analysis of safety critical tasks. Safety critical tasks relate to human failures that could result in a major accident.

The intent of this publication along with similar guidance is to achieve better integration of human failures prevention in safety studies [325].

3.7 The Role of the Safety Department and Safety Personnel

The primary role of safety personnel is to advise senior managers on all safety, health and welfare matters to ensure an organisation complies with its statutory obligations. Generally a Safety Manager (various titles may exist for this post), and subordinates, are designated responsibility by the Director accountable for health and safety to, for example:

- Understand the application of safety-related legislation relevant to a Company's business and keep up to date with any changes [45];
- Maintain sufficient competencies, e.g. skills and knowledge, to enable accurate interpretation of legislation to enable implementation within the organisation;

- Ensure effective implementation of a recognised OH&S-MS;
- Ensure that risk assessment is appropriate for the hazards created by an organisation;
- To audit and review company safety performance and make recommendations to ensure that the approach to safety is adjusted, where necessary, to meet company safety goals;
- Immediately contact the Director responsible for health and safety if situations are found, that in the opinion of the Safety Manager, require immediate rectification or the stopping of any operation;.
- To support investigations into all accidents, and near-miss incidents, and to record the findings to ensure that the OH&S-MS is modified, where necessary to prevent recurrence;
- To identify good/best safety practices and advice the organisation where appropriate as part of the process of continuous and sustainable improvements in safety; and
- To highlight areas where training/certification is required to meet the standards imposed by Legislation, Approved Codes of Practice, or H.S.E. guidance.

Consequently the role of safety personnel can be highly influential in shaping and achieving an organisation's safety goals since they provide the expertise to inform safety-related decision-making. The UK law also requires that the organisation appoints someone competent to perform health and safety duties [129]. To support this selection there is an Occupational Safety and Health Consultants Register (OSHCR) [326]. This provides an up-to-date list of general health and safety advisors who have a qualification recognised by the professional bodies participating in the scheme. A minimum standard is set for consultants to join the register. This minimum standard has been set at a degree level qualification, at least two years' experience, and active engagement in a continuing professional development scheme. All consultants who join the register are bound by their professional body's code of conduct, and are committed to providing sensible and proportionate advice. More recently, as lessons have been learnt from major accidents, there has been a new discipline of safety engineers, who have focused on major accident hazards and process safety [338].

This role has evolved to include:

- Fire safety engineering;
- Process engineering and hazard analysis;
- Hazard modelling and quantitative risk assessment,
- Process safety management; and
- Safety culture.

However, there is not a statutory requirement in the UK for an organisation to employ someone from the OSHCR. While other countries may have similar schemes, it is likely that, similar to all disciplines, there will be a wide variety in the competencies, experience and capabilities of safety professionals. Furthermore, the ability of the safety professional to help achieve safety goals is likely to be dependent on factors such as the safety culture within an organisation, the legal framework in which they operate, and the influence of the regulator.

3.8 Summary

Inherent safety

An inherently safer design is one that avoids hazards instead of controlling them, particularly by reducing the amount of hazardous material and the number of hazardous operations in the plant.

The potential benefits of an inherently safer design include:

- Less reliance on lower order process controls and active protection system;
- Less maintenance as systems are more passive;
- Less exposure to risk due to reduced maintenance;
- Lower OPEX due to reduced manpower and fewer active systems to replace;
- Improved process productivity as shut downs are less frequent; and
- Higher revenues due to increased productivity.

In the oil and gas industry the introduction of inherent safety should be relatively simple compared to complex chemical plants since the product is dominated by hydrocarbons. There is considerable literature in this field and the principles are well-defined and established. The challenges for its introduction are not technically onerous. Some work has been carried out by the UK HSE on the extent of implementation in design of inherent safety in the UK offshore oil and gas industry. It has concluded that generally the industry has been poor in adopting this approach. Currently it is not clear why the industry has not fully embraced inherent safety. However, this research suggests that, first; it may be due to the way that projects in the design phase are financed and the expectation that applying inherent safety may increase capital expenditure (CAPEX). This might compromise project viability and/or the traditional project KPIs of cost and schedule. Second, to implement inherent safety (assuming it involves higher CAPEX) would require the ability to determine lifecycle development costs. This might then justify higher CAPEX but lower operating expenditure (OPEX) so that the overall expenditure is lower compared to a non-inherently safer design. Third, safety engineers may not have the expertise to apply inherent safety, although it has been established for some time. This research has not been able to identify if this is the case but it is clear that there are no project KPIs that relate to the implementation of inherent safety during design. Fourth, this is potentially a step change from decades of traditional practice and therefore might require a culture shift in the way that the industry makes decisions. The principles of inherent safety are more specific to process and hardware systems. However, there is no literature that considers the elements of an OH&S-MS that would contribute to inherent safety. The reasons why the industry failed to fully implement inherent safety are partly speculative and more research is needed to understand its reluctance, especially when the potential benefits, technically and financially, are extremely attractive. The scope of inherent safety needs to be extended to consider the wider aspects of OH&S-MSs.

Normal Accident Theory (NAT)

'Normal accidents' can be translated as accidents that are inevitable. This is because complexity and tight-coupling of plant design and layout make it impossible to understand all the possible failure permutations and therefore controls cannot be applied to failures that cannot be predicted. The benefit of this theory is to support decision-making for plant design to ensure that complex, tightly-coupled plants with low societal value may not be constructed. If there is value in a particular plant then providing that the assessment of risk is correct, and risk tolerability and ALARP can be demonstrated, in combination with public support for the development through informed consultation, then the resultant risk can be justified. Nuclear and petrochemical plants are used to illustrate NAT. Ironically NAT states that complex, tightly-coupled plants are more efficient than alternatives. The literature does not explore this in much detail. For example, if NAT was an accepted theory that steered design then it would present a dichotomy for designers, e.g. should it be an efficient design, but accept inevitable accidents, or an inefficient design that minimises accidents? Given the weighting typically exhibited by oil and gas companies, in this context, it is likely to be the former. However, NAT fails to address more basic principles, in that if NAT was accepted theory then it might, for example, highlight the need for designers to remove people from the hazard and therefore rely more on remotely controlled facilities although this aspect of NAT is not fully explored. Furthermore, NAT fails to recognise the contribution of inherent safety which indirectly accepts that accidents might happen. Inherent safety ensures that both the likelihood and consequences (immediate and escalation), i.e. the risk, are accommodated in the design so that the effects of any failure, whether predicted in the design or not, are mitigated to ensure risk tolerability and ALARP. NAT also assumes that since operators cannot be expected to make decisions, e.g. in an emergency, to manage events that have not been predicted, and therefore for which they have no experience, then they cannot be liable for any errors they make.

This is also readily acknowledged by most companies in the industry through concepts such as 'just culture' and in the UK legal system through criminal and civil proceedings. Whereas inherent safety provides an engineer with tangible and practical design solutions, NAT is largely conceptual. The meaning of complex and tightly-coupled has no definition to which an engineer can justify a particular plant design. Also, the features of a complex, tightly-coupled chemical plant, e.g. layout, may vary considerably from a petrochemical plant with a similar footprint. Equally an onshore petrochemical plant with an identical design to an offshore facility may have different footprints but the onshore may be regarded as non-complex, loosely-coupled whereas the offshore facility could be complex and tightly-coupled. NAT offers a conceptual explanation for major accidents but lacks technical evaluation and the ability to translate the concept to inform plant design decision-making.

Resilient Engineering (RE)

In RE traditional approaches to safety management are considered to be incremental so that when a failure occurs, a change is introduced to prevent recurrence, and so on. RE believes this approach has limited value in that the change may only be just sufficient for each problem rather than a more holistic evaluation and remedy. RE attempts a step change by introducing a new way of thinking about safety management. In RE, organisations with a good or poor safety performance are expected to invest in anticipating the changing potential for failure because knowledge gaps are imperfect and the environment is constantly changing. Therefore RE is about the ability to predict the changes in risk, before failure and harm occurs. The benefit of RE is that the approach is analogous to a process system that has inputs, a process for converting them into desired outputs, and a feedback loop that continually adjusts the inputs to correct errors or deviations from required outputs. This model is tried and tested in many process-related applications and conceptually works well for managing safety performance.

In theory it ensures that systems behaviour, e.g. process, organisational, assets, is maintained within a stable range and any change towards a less stable condition is identified, in a timely way, and corrected, thereby retaining a stable state. This requires monitoring and measuring system performance to provide the accuracy, validity and speed to make modifications before harm or adverse failure occurs. In this context the theory is relatively simple. RE does emphasise, or re-emphasise some important characteristics that can contribute towards improving safety performance, e.g. that safety performance can be eroded under pressure, past good safety performance is taken as a confident predictor of future performance, etc. This approach is also found in OH&S-MSs but is not articulated in the same way, i.e. it is less obvious. The literature, similar to NAT, does not fully describe how RE translates into practice. For example, for RE to work it advocates the need to have buffering capacity to absorb deviations from a stable condition before they become unstable, i.e. produce undesired outcomes. It also requires that there is a need to manage goal conflicts to avoid relationships that can erode resilience. In both cases it is not clear how they are reconciled and RE itself does not appear to offer solutions that are any different to those currently employed by the industry, e.g. organisational structure, communications, competence, etc. RE requires that systems need to be flexible rather than stiff, i.e. to respond to change in a timely and resolute way. Similarly it is necessary to understand when a system is operating close to performance boundaries, and how the system responds when it is close to those boundaries. However, these systems, e.g. organisational, hardware, people, are never fully defined so that it is unclear what might constitute performance boundaries, how a stable condition is defined, how deviations are monitored and measured, and what would be regarded as a deviation towards a less stable state, etc. RE in this research seems no more than a concept requiring greater attention for effective implementation of an OH&S-MS. While the vocabulary might have changed and some elements of the OH&S-MS emphasised, e.g. measuring performance, its added value as a means of improving safety performance is limited at best, and at worst can cause a distraction from getting effective application of an OH&S-MS.

High Reliability Organisations (HROs)

These are organisations that are able to manage and sustain almost error-free performance despite operating in hazardous conditions (where the consequences of errors could be catastrophic) with a positive safety culture. In some respects they present similar characteristics to those of RE, and parts of NAT, in that they exhibit the need to contain unexpected events, e.g. redundancy, training, etc., require problem anticipation, e.g. sensitivity to operations that might drift to an unstable state, and are particularly relevant to complex, tightly-coupled systems. Where HROs differ from RE and NAT is the need to have a 'just' and learning culture, e.g. to report events without fear of blame and continuous training, and 'mindful' leadership, e.g. management by exception and proactive audits. In addition to the benefits of RE for which there are many parallels, HROs place additional emphasis on organisations so that they are more open to allow empowerment of decision-making to individuals. This allows systems to be readily adapted to changing conditions (similar to RE where flexibility is preferred to stiffness). As with RE, HROs invest heavily in safety management to provide an organisation with the resources it needs to meet safety objectives. Similar to RE, HROs do not have a specific framework on which to pin strategies to improvement safety performance. The concepts are not inconsistent with RE or traditional OH&S-MSs. HROs emphasis the need to invest in safety management and therefore to provide the resources necessary to satisfy safety objectives, but similar to RE and OH&S-MSs it does not describe how these resources can be funded, other than it needs a positive safety culture to happen. In some areas translating the characteristics of an HRO into practice is as difficult as those described in RE. For example, the concept that to contain unexpected events requires deference to expertise is a reasonable principle but it is doubtful if this adds value to existing practice. Similarly to have procedures to accommodate unexpected events is no different to having emergency or contingency procedures that are relatively standard in most hazardous operations. The learning culture is simply about acquiring people with the necessary skills and knowledge, e.g. competency, and experience to execute the work they are employed to do. A key

characteristic of an HRO is their apparent level of investment in safety management but there is no indication, in the literature, of how much of an organisation's budget should be committed to resourcing safety management, and whether this differs from that in any other organisation. Consequently, it could simply be that these organisations are just more effective at implementing an OH&S-MS than other comparable organisations. However, if safety management does get a greater slice of the budget, in comparable terms with other organisations, then it could create a benchmark for other organisations to follow if they desire similar levels of safety performance. It would also be interesting to understand how the safety-related resources are distributed in an HRO to help target improvement strategies, e.g. measuring performance and human factors also appear to make significant contributions to HRO performance but there is no indicator of the weighting given to either component.

Human Factors

In this research human factors refer to environmental (working), organisational and job factors, and human and individual characteristics, which influence behaviour at work in a way which can affect health and safety. This relates to what people are being asked to do (task and environment), who is doing it (competence) and where they are working (organisation). These are influenced by external factors, political, economic, technical, etc. Human factors therefore relate to all oil and gas activities, from design through to abandonment of facilities. Managing human failures is essential to prevent major accidents, occupational accidents and ill health, all of which can cost businesses money, reputation and potentially the continued viability of an organisation. Human factors pervade all aspects of oil and gas operations, and the implementation of OH&S-MSs. People carry out risk assessments, conduct incident investigations, apply company procedures, maintain safety critical equipment, and design facilities, and so on. However, it is recognised that people are considered to be the largest contributor to accidents and there are many causes, such as fatigue and shift work, behaviours, errors, lack of competence, workload, etc.

Therefore the literature examines some of these issues by taking a relatively generic approach. In some respects, given the extent of potential failure due to human factors, there is support for NAT since it is generally impossible to predict, at work, whether an individual will perform an intentional or unintentional error at any one time or situation. Therefore, in this context, failures might be considered inevitable. However, the literature on human factors does not link well with the principles of inherent safety, especially as inherent safety is the one concept, in this research, that has tangible measures to deal with failure. The concept assumes that human failures are not random but that there are patterns, and therefore understanding these patterns can help prevent error. While there are well understood causes of human failure and many of these can be remedied through training, supervision, ensuring compliance with procedures and motivational and incentive schemes, etc., it is not clear what the relationship is between human factors, in the context of decision-making and safety culture, as safety culture is considered an important factor in establishing, and delivering, safety goals.

4. RESEARCH DESIGN AND METHODOLOGY

4.1 Introduction

The hypotheses and literature review formed the basis for subsequent research using deductive and inductive methodologies. In general, deductive research is considered to be theory-testing, while inductive research is theory-generating. This research uses a combination of both. The deductive element is mainly quantitative to determine global oil and gas safety performance. The inductive element is qualitative to assess the effectiveness of Occupational Health and Safety Management Systems, their key components, and regulator influence. Consequently, the research is set out as follows:

- Case studies;
- Database analysis;
- Questionnaire; and
- Interviews.

4.2 Case Studies

Four case studies were used in this research. A key, and relatively unique, feature of using them is that they provide a comparative assessment of major accident causation over a period of 22 years. The case studies include the Piper Alpha disaster that occurred in 1988, with 167 fatalities (Figure 4 and Figure 5). The second disaster in 2005 at Texas City cost 15 lives, the third at Buncefield had no fatalities but wide ranging economic impacts, and the fourth, Deepwater Horizon in the Gulf of Mexico, in 2010 had 11 fatalities (Figure 8).

4.3 Database Analysis

A number of organisations publish oil and gas industry performance data. Primary data was extracted to identify historical safety performance. While there are issues about the validity and accuracy of the data, it has nevertheless been collected, collated, analysed and presented in

similar formats for many years and therefore provides a useful form of reference and comparison of performance. However, most of the data is provided on a voluntary basis, it conforms to a prescribed [limited] format, and not all oil and gas companies submit data. Therefore this is not a comprehensive set of safety performance data.

4.4 Questionnaire

The aim of the questionnaire used in this research was to assess whether a selected population of experienced, suitably qualified and competent oil and gas personnel:

- agreed with the general conclusions identified in the Literature Review;
- could provide explanations for their views; and
- could offer alternative views or explanations.

The survey population was restricted to people with suitable experience and competencies in the oil and gas industry, and who were particularly in safety roles. Given the characteristics of the research and the specialist disciplines, it was necessary to adopt a non-probability, non-random, sampling regime and therefore identify specific responders that would have similar competencies, e.g. skills, qualifications and experience in safety. Consequently, judgment (purposive) sampling was used [339]. This method relies on the judgment of the person carrying out the survey to select a sample that reflects the general characteristics of the target population. The advantage of this method is that it is a relatively simple, but effective, means to calibrate the findings from the research previously undertaken in this thesis. It is recognised, however, that the disadvantage of this method is the reliance on the objectivity of the person carrying out the survey and introduction of bias from any preconceived views that exist.

The sample size can be chosen in different ways but in this case the size was based on an expedient approach although it is appreciated that it lacks statistical confidence. The selection of judgment sampling relates to the choice of responders who are most advantageously placed or in the best position to provide the information required.

They could reasonably be expected to have expert knowledge by virtue of having gone through the experience and similar processes themselves and be able to provide good data or information for this research. Thus this approach is justified when a limited number or category of people have the information that is sought. In such cases any type of probability sampling across a cross-section of the entire population is purposeless and not useful.

Judgment sampling may have limitations given the restricted availability of experts. However, it is the only viable sampling method for obtaining the type of information that is required from very specific pockets of people who are very knowledgeable.

For this reason, these findings cannot be generalised to the broader community based on this study alone. It is recognised that a small sample size can have profound effects on the outcome and value of a study. On the other hand, by carefully considering what sort of hypothesis to evaluate, it was possible to find strong enough signals in the results to test conclusions relatively rigorously. Therefore, given that technical safety engineering is a relatively new discipline, it was more relevant to this research to focus on a representative set of individuals with suitable technical safety qualifications and experience, who are distinguishable from the broader range of safety professionals in the oil and gas industry, to intellectually test the research hypotheses. Naturally, future research may extend this sample size. Sample size was also restricted by access to people due to their geographical mobility and, in some cases, corporate sensitivities that inhibited participation in external surveys.

Consequently, this approach overcame the potential problem of using a large range of safety personnel with limited experience and competencies that might skew the results. It is recognised that this introduces a potential bias in the research, but this is compensated for by the combination of case studies, deductive research, options for open responses in the questionnaires, and follow-up and interviews that included people who did not take part in the questionnaire. People who had not previously taken part in the questionnaire provided views that were not biased by completing the questionnaire thereby providing a further calibration of the results.

The survey was distributed to 60 individuals and 46 responses were completed giving a response rate of ca 77%.

The questionnaire was based on the findings from the Literature Review. Given that the questionnaire attempted to address a wide range of safety issues, at best this could only be regarded as a screening exercise. Consequently, the questions were, in some cases, relatively complex, but a compromise was necessary between question complexity and the number of questions asked, i.e. some questions could have been divided to provide more specific and detailed analysis. However, this was largely compensated for by targeting respondents.

Respondents were from different oil and gas companies and included Operators, and suppliers of accommodation vessels, drilling support services and onshore plants. Geographically they covered Europe, the Middle East, Australia and New Zealand. Some respondents had experience of working in the U.S. The survey population also included both oil and gas staff, and contractors and consultants. Given the sampling criteria, it was crucial that the survey population was representative of the oil and gas industry for the purposes of this research. The questionnaire was distributed using a propriety software application, SurveyMonkey [340]. This application allowed multiple-choice question types and the results could be downloaded into a spreadsheet for detailed analysis.

A pilot questionnaire was run to spot any flaws which could then be corrected before publishing and distributing the main survey. It was delivered to a small sample of the intended respondents.

Pie charts were then produced to show the results graphically. Question 1 asked for details of each respondent and has not been included, in this thesis, to protect confidentiality.

Question 100 was an open question not requiring statistical analysis

The following options were available in response to each of the questions:

- Agree
- Disagree
- Neither agree or disagree, e.g. assumes respondent understands the question and has sufficient knowledge and experience of its relevance.
- Don't know, e.g. respondent may not understand the question or has no, or insufficient, knowledge or experience to formulate a response
- See comments, e.g. provides the option to explain or clarify a response given above, or where there is no response in the above categories, to offer an explanation.

4.5 Semi-structured Interviews

A structured interview has a formalised, limited set of questions; a semi-structured interview is flexible, allowing new questions to be brought up during the interview as a result of what the interviewee says. In this research semi structured-interviews provided greater opportunity to explore research topics in more detail. The purpose of the semi-structured interviews was to:

- Obtain specific qualitative information from a sample of the respondents;
- Obtain general information relevant to this research, (i.e. to probe for what is not known);
and
- Gain a range of insights on specific issues

The major benefits of the semi-structured interviews were that they:

- Encouraged two-way communication. Those being interviewed could ask questions of the interviewer. In this way it also functioned as an extension tool.
- Confirmed what was already known but also provided the opportunity for learning. Often the information obtained from semi-structured interviews provided not just answers, but the reasons for the answers.
- Allowed individuals to easily discuss sensitive issues.

The surveys were based on an online questionnaire that included options for both closed and open questions. The advantages of a questionnaire are:

- The data gathered is in a given format and therefore, easy to analyse;
- Data can be gathered quickly from a large number of respondents, especially given the geographical diversity and associated time zone differences of potential respondents in the global oil and gas industry ;
- Respondents can answer anonymously which may produce more honest answers; and
- The results can be readily processed.

The main disadvantages are:

- Responses may be inaccurate, especially through mis-interpretation of questions in self-completing questionnaires (although the opportunity for this was minimised by the use of a pilot questionnaire);
- A reasonable sample size is needed before the responses can be used to represent the population as a whole; and
- Response rates can be poor, if people lack the motivation to complete or return the questionnaire.

The semi-structured interviews, and possible topics for discussion, were based on some of the key findings from this research, including:

- a. OH&S-MSs
- b. Inherent safety
- c. Normal accidents
- d. Resilient engineering
- e. High reliability organisations
- f. Human factors
- g. Deductive research; and

h. The Questionnaire.

Telephone and face-to-face interviews were carried out. A pilot was undertaken to attain familiarity with the questions, and get feedback on two-way communication skills. Where possible, the interview was recorded. If this was not possible, brief notes were made during the interview and elaborated on soon after completion. Analysis of the information was carried out at the end of each day of interviewing, or as soon as possible after that. A lot of extra information surfaced during the interviews, and it was necessary to assure the person being interviewed that the information was both confidential and anonymous. All semi-structured interviews were carried out on a one-to-one basis, rather than in a group to avoid people interrupting one another or 'helping each other out', or not taking turns.

Analysis of the interviews was carried out using an abridged version of 'Content Analysis'. Content Analysis is a research tool used to determine the presence of certain words or statements within texts or sets of texts. This can be used to make inferences about the messages within the texts. To conduct a content analysis on any such text, the text is coded, or broken down, into manageable categories on a variety of levels such as word sense, phrase, sentence, or theme, and then examined using one of content analysis' basic methods: conceptual analysis or relational analysis. However, in this case, given the commonality of themes, and by using semi-structured interview techniques, the coding was intrinsic during the interview sessions, and therefore conceptual or relational analysis was readily identified [341].

4.6 Summary

The research was designed to satisfy the research objectives of:

- Reviewing case studies of selected disasters which have occurred over a suitable period, that, perhaps with the exception of the Deepwater Horizon disaster, should have allowed lessons learnt to be embedded in industry hazard management systems, and prevent future disasters (Case Studies);

- Examining the industry's historical safety performance to assess whether it can demonstrate a continuous and sustainable safety performance (Database Analysis);
- Assessing those management factors that might have an impact on the ability to deliver OH&S objectives (Questionnaire and Interviews);
- Evaluating the effectiveness and role of safety legislation and the safety regulator (Questionnaire and Interviews);
- Considering typical hazards and how the industry currently approaches safety [risk] management, during the lifecycle of a typical development (Questionnaire and Interviews); and
- Reviewing relatively new concepts of inherent safety, high reliability organisations, resilient engineering and human factors, to assess their potential value in meeting industry safety objectives, and how well they have been implemented by the industry (Questionnaire and Interviews).

5. CASE STUDIES

5.1 Introduction

The relevance of the four disaster case studies selected was that:

- They were subject to comprehensive investigation by authoritative and independent nationally-recognised bodies [6, 10, 18, 21];
- The reports were readily available in the public domain;
- Analysis of the four disaster reports provided an insight into the effectiveness of the application of OH&S-MSs, since HSG65 was first published by the UK Health and Safety Executive in 1991, approximately 3 years post-Piper Alpha, and preceding Texas City and Buncefield by about 14 years, and Deepwater Horizon by 22 years;
- The companies accountable for the disasters were all mature major petrochemical organisations with global offshore and onshore interests and therefore representative of the industry (e.g. Occidental was the owner of Piper Alpha, BP the owner of the Texas City refinery and Macondo well which was drilled by Transocean, owner of the drilling rig Deepwater Horizon, while Total UK Ltd, Chevron Ltd, BP Oil UK Ltd and Shell Oil UK were partners owning Buncefield);
- There were ample learning opportunities in the periods between the disasters, with the exception of Deepwater Horizon, to have learnt the lessons from the investigations, that, if effectively implemented, might have prevented subsequent disasters;
- All four disaster locations were subject to independent regulatory safety inspections; and
- The case studies provided a representative spread of oil and gas companies and contractors, onshore and offshore operations, and drilling and production.

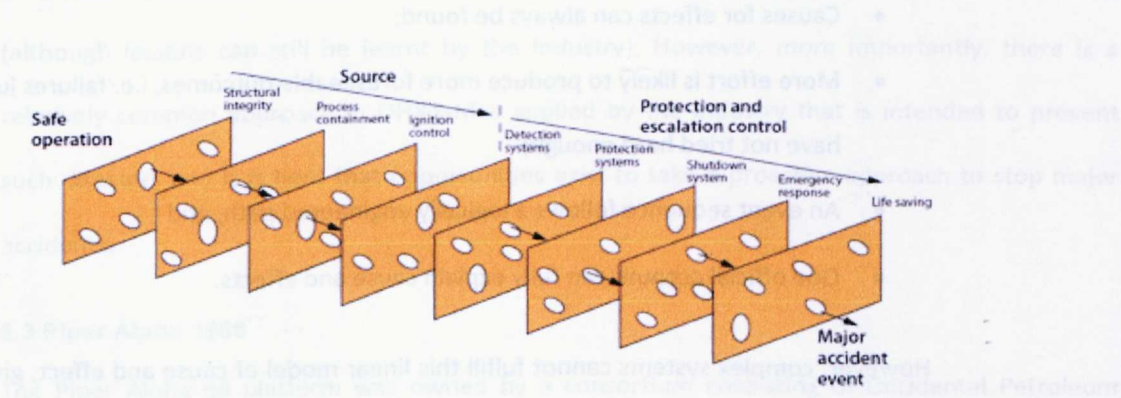
The intention was not a comprehensive analysis of the four disasters, but simply a review of the respective investigation reports for elements of commonality and contrast in relation to

immediate and root causes, i.e. the identification of the factors that could help prevent future major accidents. Piper Alpha was selected as the first case study, since it preceded the introduction of HSG 65 by three years and was, arguably, the first major accident where the facility was subject to a reasonably comprehensive prescriptive regulatory regime. It also provided the global industry with one of the most detailed public inquiries carried out to date at that time, therefore giving the industry significant learnings to help prevent future major accidents.

5.2 Accident Investigations

Before embarking on a review of the four disaster investigation reports it is worth examining whether all investigations provide the level of analysis that yields results to enable the industry, and others, to identify all causes, in sufficient depth, to prevent recurrence. While many accident investigations appear thorough, some would argue that most investigation techniques are based on a linear approach, such as the Swiss Cheese Model, Figure 24 below, involving a chain of events that often ignores the complex relationships that exist in large organisations.

Figure 24 Example of the Swiss Cheese Model
Source BG Group



This aspect should be considered in the accounts given below of the major accident investigations, since often their technical and linear bias may not explain some of the organisational and external decisions that ultimately created the conditions for a major accident

to occur. Furthermore, many accidents are believed to be caused by human error, and between 1999 and 2006, 96% of investigated U.S. aviation accidents were mainly attributed to the flight crew, and in 81%, people were the sole reported cause [342]. However, it is argued that these single factor judgmental explanations, which are dependent on a linear or 'chain of events' accident causation philosophy, cannot fully explain accident causation, since failure is embedded in complex systems and emerges as a result of a network of complex causal interactions [343]. The 'defences in depth' approach commonly used to both prevent accidents and identify potential failures (e.g. Swiss cheese model, Layers of protection Analysis (LOPA), etc), provides symmetry between cause and effect and therefore implies that events can be predicted. If events can be predicted, then measures can be taken to ensure that adequate controls are in place to prevent failures. In this context the vast majority of failures should be foreseeable and therefore people must be negligent when failures occur, hence the large percentage of accidents attributed to people. The implications are that, in linear analysis, the relationship between component behaviour and system behaviour is analytically non-problematic, and that:

- Causes for effects can always be found;
- More effort is likely to produce more foreseeable outcomes, i.e. failures just mean people have not tried hard enough;
- An event sequence follows a logically engineered path; and
- One official account can fully explain cause and effects.

However, complex systems cannot fulfill this linear model of cause and effect, given the dynamic network of relationships in a nominally regulated environment including cultural, educational, language and hierarchical diversity. Everyday decisions are embedded in masses of similar decisions and people cannot be held accountable based on the benefit of hindsight as outcomes are complex, non-linear and probably impossible to foresee (foreseeable in this context is where a

reasonable person would be able to predict or expect the ultimately harmful result of their actions [344], e.g. a foreseeable event or time is one that can easily be imagined or known about before it happens. Complexity argues that potential failures are suspended in the messy interior of the organisation, and are hard to trace as they do not follow documented organisational protocol but depend on unwritten routines, implicit expectations, professional judgments and subtle oral influences. Consequently, it is impossible to find all of the causes of failure or the true causes. It is also noteworthy that investigations tend to address both the immediate and root causes of accidents. The immediate cause, paraphrased from a legal definition [345], may be defined as the final act(s) in a series of events leading to a particular result or event, directly producing such result without further intervention, e.g. process failures that directly cause loss of containment following by ignition. Immediate causes generally relate to people, processes and practices while root causes tend to be embedded in failures of an OH&S-MS, e.g. failure to provide adequate resources to manage the risk, such as provision of competent personnel. Consequently the failures that are particularly visible, such as the disasters discussed below, all have relatively unique immediate causes and therefore are considered on a case-by-case basis (although lessons can still be learnt by the industry). However, more importantly, there is a relatively common approach in OH&S-MSs applied by the industry that is intended to prevent such disasters and it is here that opportunities exist to take a proactive approach to stop major accidents.

5.3 Piper Alpha 1988

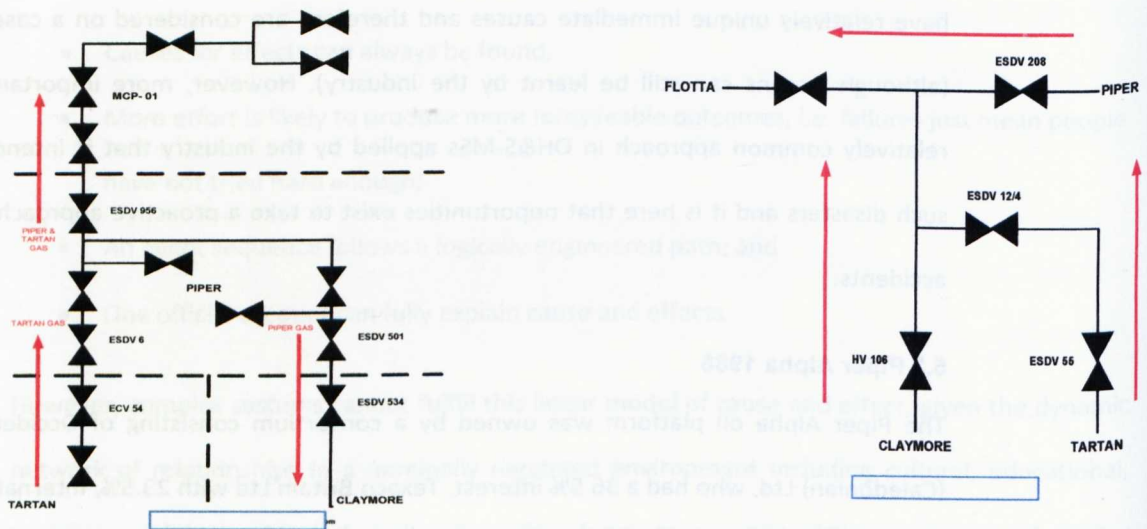
The Piper Alpha oil platform was owned by a consortium consisting of Occidental Petroleum (Caledonian) Ltd, who had a 36.5% interest, Texaco Britain Ltd with 23.5%, International Thomson PLC with 20% and Texas Petroleum Ltd with 20%. Oil was discovered in the Piper field in Block 15/17 in January 1973.

The oil field was exploited by the Piper Alpha platform. The platform was located 120 miles north-east of Aberdeen. The platform provided the facilities to drill and produce wells. The composition of produced fluids from the reservoir included a mixture of oil, gas and water. Gas and water were separated from the oil in separators, and gas condensate liquid was separated from the gas. The design flowrate was 250,000bbl/d oil. Production started in late 1976. Initially only the oil was exported to shore, by a pipeline to the onshore oil terminal at Flotta. The gas was flared until 1978 when gas surplus to platform requirements was purified and pumped to the MCP-01 gas compression platform, mingled with Frigg gas and then pumped to the British Gas collection plant at St Fergus.

Piper Alpha was connected to other platforms and to shore by 4 pipelines, 1 oil and 3 gas (Figure 25). The risers of the Main Oil Line (MOL) and gas pipelines from Tartan and to Claymore came up the north face; that of the gas pipeline to MCP-01 up the east face.

Figure 25 Piper Alpha Oil and Gas Pipelines

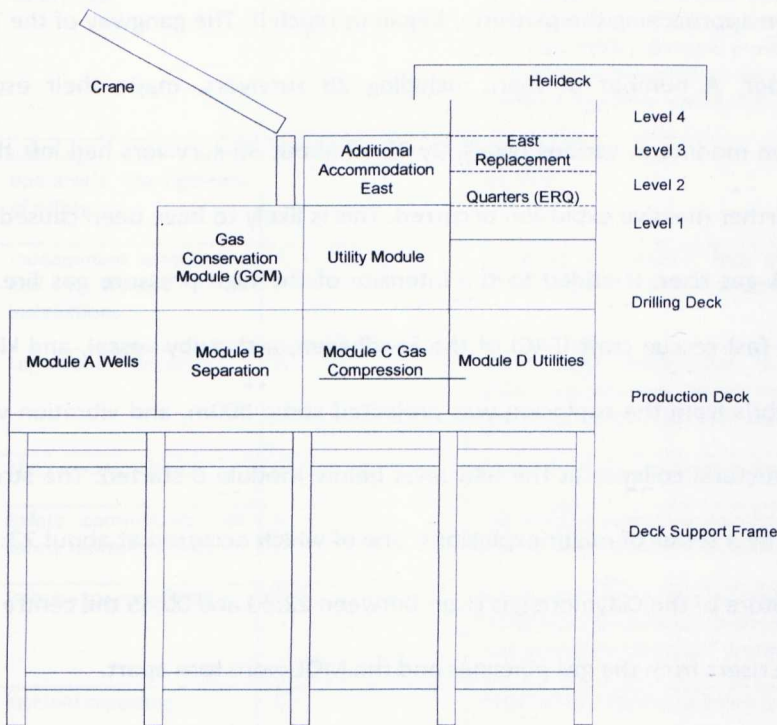
Source: The Public Inquiry into the Piper Alpha Disaster



There were various aspects of the platform in early July 1988 which were unusual, and prior to the disaster there were hydrocarbon releases involving temporary evacuation and precautionary

shutdowns. The initial explosion of the disaster occurred on the production deck at about 22:00hrs on 6 July 1988. This was followed immediately by a fire at the west end of Module B and a fireball which erupted from its west face. The fire spread rapidly in Module B and extended to Module C and down to the 68ft level (Figure 26). From the outset dense black smoke from the fire engulfed the upper parts of the northern end of the platform, due to an oil pool fire in Module B. The initial explosion was followed by a series of smaller explosions. Most of the emergency systems of the platform, including the fire water system, failed to operate.

Figure 26 Layout of Piper Alpha



Piper Alpha - East Elevation (Simplified)

At the time of the initial explosion 226 persons were onboard, of which 62 were on the night shift. The great majority of the remainder were in the accommodation module. Between 22:04 and 22:08 hrs, 3 maydays were sent from the Radio Room. The 3rd announced that the room was being abandoned due to fire, but owing to the flames and dense smoke outside the

accommodation module it was impossible for evacuation to be carried out by helicopters or lifeboats. The remaining survivors, who were on duty, made their way to the accommodation module, perhaps fully aware of the dire situation there. The normal lighting in the accommodation module failed shortly after the initial explosion, and it was followed by emergency lighting that lasted 10-15 minutes. At about 22:20 hrs there was a massive explosion which was due to the rupture of the Tartan gas riser. This caused a massive and prolonged high pressure gas fire which generated intense heat. Shortly before 22:45 hrs the cascade from the fire monitors of the Tharos, a large semi-submersible firefighting, rescue and accommodation vessel, which had been approaching the platform, began to reach it. The gangway of the Tharos was not landed on Piper. A number of men, including 28 survivors, made their escape from the accommodation module at various levels. By 22:50 about 39 survivors had left the platform. At that point a further massive explosion occurred. This is likely to have been caused by the rupture of the MCP-01 gas riser. It added to the intensity of the high pressure gas fire. The explosion destroyed the fast rescue craft (FRC) of the Sandhaven, a standby vessel, and killed most of its occupants. Debris from the explosion was projected some 800m, and vibration was felt up to a mile away. Structural collapse at the 68ft level below Module B started. The structural collapse was hastened by a series of major explosions, one of which occurred at about 23:20 hrs, and was due to the rupture of the Claymore gas riser. Between 22:30 and 00:45 the centre of the platform collapsed. The risers from the gas pipelines and the MOL were torn apart.

A total of 62 survivors from Piper (one of whom died later in hospital) and one survivor from the Sandhaven's FRC had by then reached a variety of vessels. The bodies of 30 personnel from Piper remain missing.

The Inquiry into the Piper Alpha Disaster, at that time, was probably one of the most comprehensive investigations ever undertaken into a disaster in the oil and gas industry. Its report comprised two volumes, each over 250 pages long.

The Report made 106 recommendations to improve safety performance in the UK offshore industry, summarised in Table 14.

Table 14 Piper Alpha Summary of Recommendations

Subject	Number of Recommendations	Comments
Safety Case	13	Has to demonstrate that the SMS is adequate for design and operation. Major accidents hazards are properly identified, assessed and controlled. Adequate provision to protect people in relation to emergencies. Standards to be set to ALARP. Adequate provision for escape, evacuation and rescue. Safety case to be managed.
Auditing of the operator's management of safety	2	Operator and regulatory body to satisfy themselves that SMS is working
Independent assessment and surveys of installations	1	Regulator to consider how much of the previous independent certification scheme is to be retained
Legislation – General	6	Move from prescriptive to goal-setting regulatory regime. Revocation of some existing regulations and introduction of some new ones based on goal-setting principles
The regulatory body	4	Provision of single regulatory body to UK HSE
Safety committees and safety representatives	5	The need to involve the workforce in safety, and protection of safety representatives against victimisation
Permits to work (PtW)	7	PtW should be part of SMS. Sets out need for competent PtW users. Preference to harmonise PtWs across the industry. Requirement for mechanical isolations and procedures. Display of PtW
Incident reporting	1	Regulator to maintain a hydrocarbon leak database
Control of the process	3	Key processes to be monitored from a Control Room with trained operators
Hydrocarbon inventory, risers and pipelines	4	Provision for riser isolation valves with full emergency shutdown capability. Also, Subsea Isolation valves (SSIVs) where appropriate.
Fire and gas detection and emergency shutdown	2	The provision of emergency shutdown valves and SSIVs, if fitted, should be part of the safety case and take account of emergency scenarios
Fire and explosion protection	6	The requirement to undertake a fire and explosion risk assessment and to confirm the suitability of controls and mitigations

Subject	Number of Recommendations	Comments
Accommodation, Temporary Safe Refuge (TSR), escape routes and embarkation points	7	To protect people in the TSR taking into account emergency scenarios, e.g. fire and explosion and smoke and gas ingress into the TSR
Emergency centres and systems	9	The provision of facilities in the TSR to monitor and control emergencies, including communications. To standardise (across the industry) alarm systems. To determine the vulnerability of emergency systems and standards for its availability
Pipelines emergency procedures	2	Operators to regularly review pipeline emergency procedures and manuals and shutdown procedures
Evacuation, escape and rescue – General	4	To carry out an evacuation, escape and rescue analysis and identify a number of features of this analysis that should be included, e.g. command structure
Helicopters	1	Provision for short-term availability and capacity of helicopters in the event of an emergency
Totally Enclosed Motor Propelled Survival Craft (TEMPSC)	4	Providing sufficient TEMPSC to have 150% of the persons on board (POB) the installation. To orient the TEMPSC away from the structure
Means of escape to the sea	3	To have 100% capacity of life rafts and ropes and a variety of means of descent to the sea
Personal survival and escape equipment	3	To provide people with adequate Personal Protective Equipment (PPE) including survival suit, life jacket, smoke hood, torch and fireproof gloves
Standby vessels	9	Introduction of new standards including criteria for improving rescue and recovery, crew fitness and training. In particular special training for coxswain and fast rescue craft crews.
Command in emergencies	3	The formal emergency command structure and criteria for OIM selection should be part of the SMS. There should be a system of emergency exercises
Drills, exercises and precautionary musters and evacuations	5	Emergency drills and exercises should be part of the SMS. All staff should attend one muster per tour of duty. The need to report all precautionary musters and evacuations. Need to maintain a POB list
Training for emergencies	2	Establishes the minimum requirements for offshore emergency safety training, the need to keep a register of trained personnel and that the system for emergency training and its enforcement is part of the SMS
Total	106	

However, since many of the oil and gas companies operate internationally these findings and recommendations could be cascaded and implemented globally, although there is no evidence to suggest this was done.

Relevant regulators across the globe had access to these findings to support their legislative regimes. In general, the Report was well received by the industry and it led to significant changes in the way safety was managed, particularly in respect of major hazards. However, some of the fundamental causes of the disaster were not fully explored during the Inquiry, and this is still having an impact on the way in which the industry manages safety. For example, it was documented in the Inquiry Report that, following the initial explosion that must have consumed most of the hazardous inventory on Piper Alpha, any subsequent explosions must have been fed from the pipelines connected to Piper Alpha, and these pipelines were able to be shutdown at their sources.

The Report identified that there was a considerable delay in closing these pipelines, resulting in escalation of the initial event, and therefore criticised the Offshore Installation Managers (OIMs) who were responsible for managing those offshore installations that had control of the pipelines leading to Piper Alpha.

The Inquiry failed to understand why the OIMs were so reluctant to shut down their pipelines despite the fact they had received Maydays from the Piper Alpha and had been informed of the situation on the Piper Alpha by the Tharos.

If decision making by the OIMs is seen in the context that, at that time, huge investment (in excess of \$1 billion) had been made by Occidental, and that to achieve suitable margins, costs had to be driven down and revenue maximised by oil and gas production, then the pressure to maintain production is likely to have been immense.

However, the Inquiry tended to focus on the technical aspects and heavily biased the recommendations as illustrated in Table 14. Noticeable is the absence of any recommendations associated with safety culture, or drivers that influence safety-related decisions and behaviours. There is nothing about safety performance and how this might have either contributed to the failures that eventually led to the disaster or provided the signs that could have prevented the disaster. However, many of the recommendations were associated with risk management and the use of ALARP in the risk analysis.

5.4 BP Texas City 2005

On March 23, 2005, at 1:20 p.m., the BP Texas City Refinery suffered one of the worst industrial disasters in recent U.S. history [18]. Explosions and fires killed 15 people and injured another 180, alarmed the community, and resulted in financial losses exceeding \$1.5 billion. At the time of the accident it was BP's largest refinery and produced 10 million gallons of gasoline per day, approximately 2.5% of the gasoline sold in the U.S. It also produced jet and diesel fuels and chemical feed stocks, and comprised 29 oil-refining units and 4 chemical units spread over its 1200-acre site. It employed approximately 1800 employees and at the time of the accident approximately 800 contractors were on site. The Texas City facility is one of five U.S. refineries owned by BP; its others are in Whiting, Indiana; Carson, California; Cherry Point, Washington; and Toledo, Ohio.

The incident occurred within the refinery's Isomerization (ISOM) unit when it was being restarted after maintenance, which had lasted for one month. The ISOM started production in 1985 to produce higher octane fuel for blending with unleaded petrol. The plant comprised:

- An Ultrafiner desulfuriser;
- A Penex reactor;
- A vapour recovery/liquid recycle unit; and

- A raffinate splitter that took stock from the Aromatics Recovery Unit (ARU) and separated light and heavy components.

The refinery and its equipment were designed and operated in accordance with Amoco and U.S. industry engineering codes and process safety standards. Following the BP-Amoco merger, former Amoco sites continued using these standards.

Between 1993 and 2002 various safety improvement projects were proposed for the site but all were rejected due to costs and regulatory uncertainty. In early 2005, two plants adjacent to the ISOM unit were shut down for maintenance and repair (turnarounds). These were the Ultracracker unit (ULC) and Aromatics Recovery Units (ARC). Trailers were provided for employees supporting the ULC, and both activities increased the number of BP personnel and contractors in the area. The raffinate splitter was shut down on 21 February 2005, and drained, purged and steam-cleaned to remove hydrocarbons. At the time of the incident the majority of planned tasks had been completed on the raffinate splitter section, but the Penex reactor, separated from the splitter, was waiting for a gasket to be fitted. When BP started up the raffinate splitter section, three contractor crews were still working on the ISOM unit: one was waiting to install the gasket on the Penex unit, another was removing some asbestos, and the third was painting the inside of the unit. The incident occurred during the startup of the raffinate splitter section of the ISOM unit, when the raffinate splitter tower was overfilled. Flammable liquid was released, which vapourised, and ignited, resulting in an explosion and fire.

Prior to the introduction of hydrocarbons, a Pre-Startup Safety Review (PSSR) should have been carried out, but it was not done. On instruction from BP, startup of the ISOM unit raffinate section was initiated during the night shift on 22 March 2005. However, after startup had begun, it was stopped and then had to be re-started during the next shift. This was unusual and was not covered in the startup procedures. Furthermore, while the night shift supervisor started filling the raffinate section he did not use the startup procedure or record what had been done and

therefore there was no description of the actual plant status for the next shift. The raffinate splitter tower was filled past the two alarms to a level reading of 99% on the transmitter in the early morning on 23 March 2005, but only one alarm was activated. For the morning of 23 March 2005, the investigation report identified various communication failures.

The flammable liquid discharged into the collection header for about 46 seconds and then into the blowdown drum, at a rate estimated to have been 509,500 gallons per hour. As this drum filled, some of the liquid flowed into the ISOM process sewer system at a rate estimated to have been 223,400 gallons per hour, and into the other safety relief valve discharge pipe headers. It was estimated that 7,600 gallons were discharged. In response, the Board Operator and Lead Operator shut the flow of fuel to the furnace, while outside operators re-directed traffic away from the blowdown drum. The ISOM operators were unable to sound the emergency alarm before the explosion. Hundreds of alarms registered in the Control Room at 13:20 hrs. The resultant vapour covered an area of approximately 200,000 square feet. However, in order for an explosion to occur, an ignition source of sufficient energy was needed to ignite the flammable gas/air mixture, and the most likely source was an idling diesel pick-up truck that was parked about 25 feet from the blowdown drum. The overpressure generated by the explosion produced heavy structural damage in all directions. The flame-front also ignited flammable liquid that had accumulated near the blow down stack, causing a pool fire. The most severe blast damage occurred within the ISOM unit and the surrounding area. Many of the approximately 70 vehicles near the ISOM unit were damaged or destroyed, and similarly, more than 40 trailers were damaged while 13 were destroyed. Buildings in the area suffered blast damage and 50 storage tanks incurred varying levels of structural damage. Blast damage also occurred in offsite premises located north of the refinery, up to a ¾ of a mile away from the ISOM unit. As a result of the incident, 15 contract employees working in the area were killed, 3 in a Quality Assurance/Quality Control (QA/QC) trailer and 12 out of 20 in a doublewide trailer; the others were seriously injured.

None of the contract workers in the area needed to have been there at the time of the incident. A total of 180 employees were injured.

The investigation stated that, *"Many of the safety problems that led to the March 23, 2005, disaster were recurring problems that had been previously identified in audits and investigations"*.

Between 1975 and 2005, The Texas City site had 23 fatalities. For example, in 2004 there were three major accidents that resulted in three fatalities. Shortly after the incident in March 2005, there were a further two incidents as a result of mechanical integrity failures, and in 2006 there was a further fatality. BP was aware of the serious safety problems at the refinery, but the focus was primarily on personal safety rather than process safety. Consequently, as personal safety statistics improved, BP Group executives assumed that performance was heading in the right direction. However, process safety, training and safety leadership performance continued to deteriorate at Texas City, primarily due to the lack of funding.

Following the 1999 BP and Amoco merger, there were a number of organisational changes that involved, for example, dismantling and decentralising safety groups. These produced cost savings, but the process safety function no longer reported directly to senior refinery executive leadership, and therefore their ability to influence decisions was adversely impacted.

BP Group's 'Getting Health, Safety, and the Environment Right' (GHSER) policy, established in 1997, was intended to provide a business-wide HSE management system. However, the GHSER policy for performance reporting was not followed, and thus serious safety failures were not identified in the reports.

BP Group issued a 'Process Safety/Integrity Management' standard in May 2001 covering design, construction, operation and maintenance, and management of major accident hazards. However, following a review of the application of the standard it was determined that the existing process safety management system covered the requirements of the standard and no change was needed. While the process safety group developed and tracked process safety performance,

unlike the conventional safety metrics relating to incident reported, the process safety metrics did not drive site performance. Consequently, plant performance contracts, personal performance contracts or bonus programmes were all excluded from the process safety management regime. The BP Group incentive programme, which was in place several years before the ISOM incident, did not include process safety management but 'cost leadership' accounted for 50% and safety metrics 10%. For 2003 – 2004 the single safety metric for the bonus was the Recordable Injury Rate.

Behavioural safety was an important feature of the BP Texas City safety management system and had been in place since 1997. Workers were required to observe and report unsafe acts and conditions. In 2001, BP Texas City managers stated that the site required a significant improvement in performance or a worker would be killed in the next three or four years. They said that unsafe acts contributed to 90% of the injuries at the refinery. In 2004, the budget and programme were further expanded for a new behaviour initiative, and this resulted in 48,000 reported safety observations, although it typically excluded safety systems, management activities, or any process safety-related activities.

BP Group and Texas City managers' priorities were greatly influenced by the industry benchmarking of Solomon Associates, a firm that provides performance analysis and benchmarking services. Solomon Associates' performance measures included operating cost, refinery utilisation, mechanical availability, energy efficiency, personnel staffing, and specific process unit categories, but did not include any process safety-related metrics.

Before 1989, the Occupational Safety and Health Administration (OSHA) had conducted a Special Emphasis Programme (SEP) using a safety system approach, to prevent accidents in the chemical manufacturing industry. This involved 40 inspections of different plants in 1985 and 1986, and identified the need for a different inspection regime to address the potential for catastrophic situations. In 1989 an explosion occurred at the Phillips 66 plant in Pasadena, Texas, killing 23

people. It was not until 1992 that OSHA introduced the OSHA Process Safety Metrics (PSM) standard. Following an investigation by OSHA into the major accident on 23 March 2005, at Texas City, OSHA identified over 300 wilful violations of OSHA standards, many of which related to PSM non-compliance. In the previous 20 years OSHA records show there were a minimum of 10 incidents at the site resulting in 10 fatalities, and during this period OSHA issued citations for three willful and 82 serious violations, resulting in proposed penalties of \$270,255 of which \$77,860 was collected.

Before the major accident at Texas City on 23 March 2005, they had a Total Reportable Incident Rate (TRIR) that was a third of the industry average, although multiple fatalities had occurred in 2004. While OSHA were required to target five inspection sites, the selection criteria included incident history. However, in its report on the Phillips 66 explosion, OSHA concluded that the petrochemical industry had a lower accident frequency than the rest of manufacturing, when measured in traditional ways, using the Total Reportable Incident Rate (TRIR) and the Lost Time Injury Rate (LTIR). The Phillips 66 and BP Texas City explosions are examples of low-frequency, high-consequence catastrophic accidents. TRIR and LTIR do not effectively predict a facility's risk for a catastrophic event; therefore, inspection targeting should not rely on traditional injury data. While OSHA's compliance directive assumed that a comprehensive inspection would need to take several weeks or months to provide value, five out of the nine planned federal OSHA Programme Quality Verification (PQV) inspections lasted less than one month. This may have been due to resource constraints, given the estimated 15,000 facilities that needed to be covered. The National Transport Safety Board (NTSB) concluded that OSHA did not provide effective oversight of such hazardous facilities.

The Texas City investigation identified a number of root causes;

- BP Group Board did not provide effective oversight of the company's safety culture and major accident prevention programmes.

Senior executives:

- inadequately addressed controlling major hazard risks. Personal safety was measured, rewarded, and was the primary focus, but the same emphasis was not put on improving process safety performance;
- did not provide effective safety culture leadership and oversight to prevent catastrophic accidents;
- ineffectively ensured that the safety implications of major organisational, personnel, and policy changes were evaluated;
- did not provide adequate resources to prevent major accidents; budget cuts impaired process safety performance at the Texas City refinery.

BP Texas City Managers did not:

- create an effective reporting and learning culture; reporting bad news was not encouraged. Incidents were often ineffectively investigated and appropriate corrective actions not taken; and
- ensure that supervisors and management modelled and enforced the use of up-to-date plant policies and procedures, and did not incorporate good practice in the operation of the ISOM unit.

In terms of contributory causes, BP Texas City managers:

- lacked an effective mechanical integrity programme to maintain instruments and process equipment. For example, malfunctioning instruments and equipment were not repaired prior to startup;
- did not have an effective vehicle traffic policy to control vehicle traffic into hazardous process areas or to establish safe distances from process unit boundaries;
- ineffectively implemented their PSSR policy; non-essential personnel were not removed from areas in and around process units during the hazardous unit startup; and

- lacked a policy for siting trailers that was sufficiently protective of trailer occupants.

5.5 The Buncefield Oil Storage Depot 2005

Following the initial formal Investigation Report, a subsequent Report, '*Buncefield: Why did it happen?* [346]' was issued. This Report was issued several years after the original investigation report [21] because it was not possible to disclose some of the underlying causation due to ongoing legal proceedings at that time.

Located in Hemel Hempstead, Hertfordshire, England, close to Junction 8 of the M1 motorway Buncefield is an oil storage and transfer depot. There were three operating sites at the depot:

- Hertfordshire Oil Storage Ltd (HOSL), a joint venture between Total UK Ltd and Chevron Ltd, and under the day-to-day management of Total UK Ltd. HOSL (the site) was divided into East and West sites;
- British Pipeline Agency Ltd (BPA), a joint venture between BP Oil and Shell Oil UK, although the assets were owned by UK Oil Pipelines Ltd (UKOP). This tank farm was also in two parts, the north section, and the main section which was located between HOSL East and West; and
- BP Oil UK Ltd, at the southern end of the depot.

All three sites were 'top-tier' sites, under the UK Control of Major Accident Hazards Regulations 1999 (COMAH), and had planning consent to store 194,000 tonnes of hydrocarbon fuels. Fuel was transported to these sites through three pipelines:

- the Fina Line between Lindsey Oil Refinery, Humberside and the HOSL West site;
- the UKOP North line between Stanlow Oil Refinery, Merseyside and BPA; and
- the UKOP South line between Coryton Oil Refinery, Essex and BPA.

Various grades of fuel were separated into dedicated tanks according to the fuel type, and the majority of fuel was then taken from the depot by road tankers. The report states that, *"unleaded petrol was being delivered through the UKOP South line into HOSL's Tank 912 from 1850 hrs on Saturday 10 December 2005. The tank, which had a capacity of 6 million litres, was fitted with an automatic tank gauging system (ATG) which measured the rising level of fuel and displayed this on a screen in the control room. At 0305 hrs on Sunday 11 December the ATG display 'flatlined', that is, it stopped registering the rising level of fuel in the tank although the tank continued to fill. Consequently the three ATG alarms, the 'user level', the 'high level' and the 'high-high level', could not operate as the tank reading was always below these alarm levels. Due to the practice of working to alarms in the control room, the control room supervisor was not alerted to the fact that the tank was at risk of overfilling. The level of petrol in the tank continued to rise unchecked. The tank was also fitted with an independent high-level switch (IHLS) set at a higher level than the ATG alarms. This was intended to stop the filling process by automatically closing valves on any pipelines importing product, as well as sounding an audible alarm should the petrol in the tank reach an unintended high level. The IHLS also failed to register the rising level of petrol, so the 'final alarm' did not sound and the automatic shutdown was not activated. By 0537 hrs on 11 December, the level within the tank exceeded its ultimate capacity and petrol started to spill out of vents in the tank roof".*

Vapour was noticed by members of the public and by tanker drivers who alerted site employees, and the alarm was activated, as was the site fire pump. A vapour cloud explosion then occurred and the devastation far exceeded expectations. Although there were no fatalities, 40 people were injured and the subsequent fire, believed to be the largest seen in peacetime in the UK, engulfed over 20 tanks and burnt for several days.

The immediate cause of this major incident was the failure of both the ATG and the IHLS to control levels in tank 912. The following contributory factors were identified:

- Tank 912 was fitted with a new independent high-level switch on 1 July 2004 but the design, installation and maintenance of the switch was not fully understood by operators and it was left inoperable. The design was not subjected to rigorous review and therefore potential failure modes were not identified. Neither was it identified as safety critical. Supply chain failures also occurred in the alignment of specifications, communication of product data, identification of equipment vulnerabilities, and testing procedures;
- The ATG failure had flatlined 14 times between 31 August 2005 and 11 December 2005 before this incident but the actual cause of the problem was never resolved;
- The control room monitor could only view one tank at a time and therefore the operators relied heavily on the effectiveness of the tank level control system. The Red Stop emergency shutdown button on the mimic screen was supposed to close all tank side valves but, unknown to the supervisors, it had never been fitted. Although there were later versions of the ATG system with improved alarm capability, the system was never modified.

There was inadequate fault logging that should have demonstrated a history and failure trends to alert personnel to a more serious problem.

Management failures

The overall control system for the distribution of fuel on the site was fragmented and this undermined the ability of supervisors to control the management of fuel. This was exacerbated by the different priorities over the lines associated with financial penalties if the wrong flow was stopped, especially in the context that since the late 1960s there had been a four-fold increase in throughput of product on the site. This increase also meant more tankers, greater focus on ullage

management and more pressure on staff. Staff then worked overtime to meet demand, and the company recruited an additional supervisor, but another resigned so that the net effect was zero.

On the night of the incident, deficiencies in shift handover procedures led to some confusion in the control room about which pipeline was filling which tank. The control room operators did not receive any risk assessment training, and written work procedures relating to the filling process were short on detail. Consequently, there was no robust safe system of work at the site. The contractual agreements relating to the supply of safety critical equipment neglected suitable specifications relating to functionality and maintenance requirements, and replacements were not subject to a rigorous management of change procedure that might have properly assessed the safety-related implications of the change.

Loss of secondary containment

The design of the bunding around the tanks was flawed, and large volumes of fuel, firefighting foam and water spilled out of the bunds during the incident and emergency response, due to joints and penetrations through the bund.

Tertiary containment

There was essentially no tertiary containment outside the bunding other than drainage for rainwater and minor spills. Any spillage from the tanks was not directed to the drains but kept within the bunding.

Emergency arrangements

COMAH requires that adequate emergency arrangements are in place but the following provisions were either not made or were inadequate:

- Lack of risk assessment reflecting worst-case scenarios that allows emergency procedures to be informed about the best course of action;
- No up-to-date drainage plans to determine flows and associated risks for emergency response;
- No spill response contract to obtain support in the event of a major incident.

Safety management systems, managerial oversight and leadership

The site was considered, under COMAH, as top tier, and therefore required a safety report. However, what was written and submitted to the UK HSE, did not reflect what was actually practised. The management system was inadequate due to factors such as the following:

- Risk assessments only considered a single tank fire or bund failure;
- Poor management of contractors to ensure that bunding design and construction were in accordance with good practice;
- Poor application of management of change procedures;
- No review of standards to assess whether later revisions could be introduced to improve site safety;
- Bund failures were not considered as 'near-misses' and therefore opportunities were lost to improve their design, construction and maintenance.

Management of the site

The operation was managed by Total using Total employees. However, the overall responsibility for the site remained with Hertfordshire Oil Storage Ltd (HOSL) as the operator under the COMAH regulations. Total had considerable influence over site operations and were supposed to provide HOSL with engineering support and other expertise, but support was poor. This was attributed to the Operations Manager and Terminal Co-coordinator being overworked, and also their lack of

competency in some areas. Furthermore, their Loss Control Manual was not effectively implemented, which if it had been, could have prevented the incident. There was too much focus on occupational safety and too little on process safety.

The COMAH Safety Report was produced by contractors but never scrutinised by HOSL, and therefore they were oblivious to many of the provisions required for the control of major accident hazards, and had an unjustified over-confidence about site performance.

Conclusions

Based on the above findings, the investigation report concluded the following:

- *“The failed level control system was the immediate cause of the incident but the underlying, or root causes were equally important and are likely to have wider implications across all major hazard industries.*
- *The process safety controls on safety critical operations were not maintained to the highest standard;*
- *Senior managers did not apply effective control;*
- *Effective auditing systems were not in place. Auditing and monitoring arrangements focused on whether a system was in place; the audits did not test the quality of the systems and, most importantly, did not check whether they were being used or were effective.*
- *The designers, manufacturers, installers and those involved in maintenance did not have an adequate knowledge of the environment in which the equipment was to be used, and the design, installation and maintenance of safety critical equipment was just as important as the operational process controls.*
- *Operators of safety critical equipment were unable to make the right decisions about the standards they needed to apply to their work.*

- *HOSL did not act as an 'intelligent customer' and could not be assured of the service they were obtaining from their contractors.*
- *A safety report is not a chore to satisfy the regulator and HOSL missed an ideal opportunity to look critically at its own systems and managerial arrangements intended to 'prevent major accidents and limit their consequences to persons and the environment'.*

All major hazard sites are unique, but there are many common threads to the management of them. Many of the important factors are discussed in this thesis. They warrant careful consideration by the whole of the major hazard sector. The types of managerial failings revealed during the Buncefield investigation were often found at other major incidents. The report on the gas explosion at Longford, Australia in 1998 (a catastrophic explosion which occurred at the Esso natural gas plant at Longford in the Australian state of Victoria's Gippsland region, on 25 September, killing two workers and injuring eight) [312], identified factors associated with the incident which were later found at Buncefield. For example:

- *"poor communications at shift handover;*
- *lack of engineering expertise on site; and*
- *failure to implement management of change processes".*

Equally, some of the failings identified at Buncefield were also identified by Baker (the BP Texas City Investigation Report was chaired by former U.S. Secretary of State James Baker, III) in his report. In both cases management failed to address safety critical process controls. The Baker report emphasised that process safety protection systems should not rely on operator responses to alarms and that overfill protection should be independent of normal operational monitoring. Both reports also identified that leadership and top-level engagement in dealing with significant risks to people and the environment, in this industrial sector, was lacking.

The Buncefield explosion was therefore further evidence that, for at least some major hazard organisations, vital lessons from previous disasters had not been adequately captured.

5.6 Transocean Deepwater Horizon 2010

Background

The explosion, following a blowout of the Macondo well, on the Transocean drilling rig, Deepwater Horizon, occurred in April 2010, in the relatively deep waters of the Gulf of Mexico (GoM). This resulted in 11 crew fatalities, 16 injured crewmen, and a subsequent economic and environmental disaster. The full impact of the disaster is still unknown. Other than the effects on the families of the people who died, it is estimated that more than four million barrels of oil were released into the GoM, threatening various ecological systems and the livelihood of industries reliant on exploiting those natural resources. On May 22, 2010, President Barack Obama announced the creation of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling: an independent, nonpartisan entity, responsible for investigating the disaster. Their remit was to determine the causes of the disaster, and to improve the country's ability to respond to spills, and to recommend reforms to make offshore energy production safer [347].

The BP Macondo well

In March 2008, BP paid a little over \$34 million to the then Minerals Management Service (MMS) for an exclusive lease to drill in Mississippi Canyon Block 252, a nine-square-mile plot in the Gulf of Mexico. BP had contracted the drilling rig, Deepwater Horizon, owned by Transocean, to drill the Macondo well and, according to government reports, had budgeted \$96.2 million and 51 days of work to drill the well. They discovered a large reservoir of oil and gas, but drilling had been challenging. On 20 April 2010, they were almost six weeks behind schedule and more than \$58 million over budget. In addition, the Deepwater Horizon, built for \$350 million, was being leased for as much as \$1 million per day [348].

Financial Pressures and the impact on safety

The investigation revealed that technological challenges and the necessity to complete work as quickly as possible compromised safety. It painted a picture of the oil and gas industry in the U.S. where:

- Project profitability depended on how soon production could be brought online (perhaps a similar pressure was on the OIMs who failed to quickly shutdown the pipelines leading to Piper Alpha);
- Production processes were highly interdependent: delay in one place could cause delays elsewhere. Therefore there were relentless demands to drill the wells, install the platforms, and get the oil and gas flowing; and
- Drilling vessels were contracted on day-rates, increasing time pressures.

The report quoted one offshore worker as saying, *"When I first started working, they didn't care whether they killed you or not. In other words, we are going to get it done, regardless. There was no suing like people are suing now. Back then, if you got hurt, they just pushed you to the side and put somebody else in".*

Oil and gas companies had not recovered from the 1980s bust when oil prices dipped again in the late 1990s, driven in large part by the drop in global demand, precipitated by the Asian financial crisis. Consequently, there was increased shareholder pressure on oil companies to improve short-term financial results and longer-term profitability. This led to various mergers, e.g. in 1998, BP acquired Amoco. The following year, Exxon merged with Mobil in an \$80 billion deal to create the world's largest company. BP-Amoco then countered by acquiring ARCO; Total merged with Fina and Elf (renamed Total in 2003); Chevron combined with Texaco; and, finally, Conoco and Phillips joined to create the sixth 'super major' (along with Royal Dutch Shell). The purpose of the mergers was to reduce costs by, for example, sharing common support functions and

outsourcing research and development. This led to reduced staffing levels, which helped to improve financial margins. It also provided the merged companies with new capital reserves to finance the more challenging, and therefore riskier but with potentially higher return, exploration and exploitation ventures.

Nevertheless, the challenges and associated risks were viewed by the industry as manageable given the potential rewards, especially as the offshore industry had enjoyed a long run in the Gulf without an environmental catastrophe.

The major oil-service companies, such as Halliburton and Dresser also consolidated. The Transocean Offshore and Sedco Forex merger was announced in July 1999, and they eventually became Transocean. These organisations provided the oil and gas companies with a variety of services, such as drilling, evaluation, well-completion, and production services. It was during this era that offshore oil exploration and production became an increasingly global enterprise [349].

Managing Liability

The Report states, *"The market has a financial mechanism for encouraging risk-managing behaviours: the cost of insurance. In the wake of the Deepwater Horizon oil spill, early reports indicated that insurance premiums rose by as much as 15 to 25 percent in shallow waters and up to 50 percent for deepwater rigs. An energy underwriter predicted that premiums for deepwater operations would rise 25–30 percent, and by 100 percent for deepwater drilling [350]"*.

Integrity of the Deepwater drilling rig

At the time of the disaster there was a backlog of rig maintenance on the Deepwater Horizon that should have been done but was not. During September 2009, a BP safety audit produced a 30-page list of 390 items requiring 3,545 man-hours of work [348].

Role of the Regulator

When the disaster occurred, the MMS, a federal agency, was responsible for regulating offshore drilling operations, including environmental enforcement. However, only 19 days after the disaster, the U.S. Secretary of State, Ken Salazar, announced his intention to withdraw its leasing, revenue collection, and permitting functions, and to place the former within a 'separate and independent' entity. A week later, he announced that MMS would be reorganised into three separate entities with distinct missions: a Bureau of Ocean Energy Management; a Bureau of Safety and Environmental Enforcement; and an Office of Natural Resources Revenue. By June 19, the Secretary had discarded the 'MMS' name altogether. It was argued that MMS suffered a conflict of interest in that it had a built-in incentive to promote offshore drilling in sharp tension with its mandate to ensure safe drilling and environmental protection.

Revenue generation, for industry and government, became the dominant objective. There appears to have been a culture of revenue maximization, and for at least 15 years previously, every former MMS Director had freely acknowledged that the royalty issues have taken most of the Director's time, at the expense of offshore regulatory oversight. This problem, together with lack of regulatory oversight, was amplified as revenue generation was also dependent on moving drilling further offshore and into much deeper waters. However, there were commensurate increased risks that were not matched by associated regulatory management. Unfortunately, the US oil and gas industry regularly and intensely resisted greater regulatory involvement and enforcement. MMS could not force change, partly because it had no political autonomy, and no series of presidential administrations commanded the political support necessary to overcome that opposition. The Report states, *"On April 20, the inherent risks of decades of inadequate regulation, insufficient investment, and incomplete planning were realized in tragic fashion. MMS no doubt can fairly boast of many hardworking individual public servants who have in good faith sought to achieve their agency's important safety mission over sustained industry opposition. But,*

notwithstanding their individual efforts and accomplishments, the overall picture of MMS that has emerged since April 20 is distressing. MMS became an agency systematically lacking the resources, technical training, or experience in petroleum engineering that is absolutely critical to ensuring that offshore drilling is being conducted in a safe and responsible manner. For a regulatory agency to fall so short of its essential safety mission is inexcusable”.

MMS placed too much reliance on prescriptive regulation with an associated inspection model. However, the Report stated that this approach is fundamentally reactive and therefore incapable of driving continuous improvement in policies and practices. MMS did try to introduce changes to improve safety, and in July 1991, three years after Piper Alpha, proposed a strategy to promote safety and environmental protection, specifically, a requirement that outer continental shelf leasees and/or operators develop, maintain, and implement ‘a safety and environmental management programme (SEMP)’, similar to the United Kingdom’s Formal Safety Assessment or Norway’s Concept Safety Evaluation programmes. However, at the time of the Macondo blowout, almost 20 years after its original proposal, MMS had still not published a rule mandating that all operators have plans to manage safety and environmental risks. The proposal was repeatedly revisited, refined, delayed, and blocked, by industry or sceptical agency political appointees.

MMS tried to introduce a weakened version a decade later but was still unsuccessful, and then in May 2006, it finally proposed a rule on Safety and Environmental Management Systems, but this only required that 4 of the 12 widely-accepted elements of industrial process safety management be put into place. Industry opposition, even to this limited proposal, was rapid and, ultimately, it was only after the Macondo well blowout four years later that the federal agency finalised a more comprehensive, mandatory SEMP rule. Other agencies also suffered a lack of resources; the United States Coast Guard is responsible for regulating the ‘safety of life and property on Outer Continental Shelf (OCS) facilities, vessels, and other units engaged in OCS activities’. This is

because most drilling rigs and even some production platforms fall under the definition of 'vessels', and part of the responsibility for regulating their safe operation (and full authority for certifying their seaworthiness) is within the jurisdiction of the Coast Guard. However, the Report states that, *"just when the need for Coast Guard oversight increased during the 1990s—as industry drilled in deeper waters farther offshore and used more ambitious floating drilling and production systems, it, too, faced more severe budgetary restraints. Accordingly, the Coast Guard failed to update its marine-safety rules.....following the terrorist attacks of September 11, 2001, given the nation's overriding need to focus on border and port security, the Coast Guard's 'solution'—to transfer much of its responsibility for fixed platform safety to MMS"*[113].

The Immediate Causes of the Macondo Well Blowout

As with all disasters, the cause of the accident was the product of a series of failures by Transocean, BP and Halliburton and the political, economic and regulatory conditions previously discussed. The Report recognised that it may never identify the motivations behind the decisions that directly led to the blowout but it does state that, *"What we nonetheless do know is considerable and significant:*

- *each of the mistakes made on the rig and onshore by industry and government increased the risk of a well blowout;*
- *(2) the cumulative risk that resulted from these decisions and actions was both unreasonably large and avoidable; and*
- *(3) the risk of a catastrophic blowout was ultimately realized on April 20 and several of the mistakes were contributory causes of the blowout".*

The immediate cause of the Macondo blowout was the failure to contain hydrocarbon pressures in the well, and the failure to understand that the risks compromised the primary barriers designed to prevent loss of containment [351].

**The Root Causes: Failures in Industry and Government
Overarching Management Failures by Industry**

The Report is clear, in that it states that there is no uncertainty about the root causes of the blowout. The root causes were systemic failures by industry management (extending beyond BP to contractors), and also failures by government to provide effective regulatory oversight of offshore drilling. The Report cited the following as factors that might prevent future such disasters:

- *“better management of decision-making processes within BP and other companies;*
- *better communication within and between BP and its contractors;*
- *more effective training of key engineering and rig personnel;*
- *BP and other operators must have effective systems in place for integrating the various corporate cultures and internal procedures; and*
- *companies involved must have in place strict policies requiring rigorous analysis and proof that less-costly alternatives are in fact equally safe. Unless companies create and enforce such policies, there is simply too great a risk that financial pressures will systematically bias decision-making in favor of time- and cost savings”.*

The report also strongly advocated that it is critical that companies implement and maintain a pervasive top-down safety culture that rewards employees and contractors who take action when there is a safety concern, even though such action costs the company time and money.

The Government also failed to provide the oversight necessary to prevent these lapses in judgment and management by private industry [351]. The Report states:

“Safety is not proprietary.

The record shows that without effective government oversight, the offshore oil and gas industry will not adequately reduce the risk of accidents, nor prepare effectively to respond in emergencies.

However, government oversight, alone, cannot reduce those risks to the full extent possible. Government oversight must be accompanied by the oil and gas industry's internal reinvention: sweeping reforms that accomplish no less than a fundamental transformation of its safety culture. Only through such a demonstrated transformation will industry—in the aftermath of the Deepwater Horizon disaster—truly earn the privilege of access to the nation's energy resources located on federal properties...Offshore oil and gas exploration and production are risky. But even the most inherently risky industry can be made much safer, given the right incentives and disciplined systems, sustained by committed leadership and effective training"

The Report examines in more detail BP's Safety Culture, and their perception of risk, both of which were considered to be flawed. A safety survey carried out by Transocean of its employees, prior to the disaster, also revealed that 34% of the workforce feared reprisals for reporting unsafe situations.

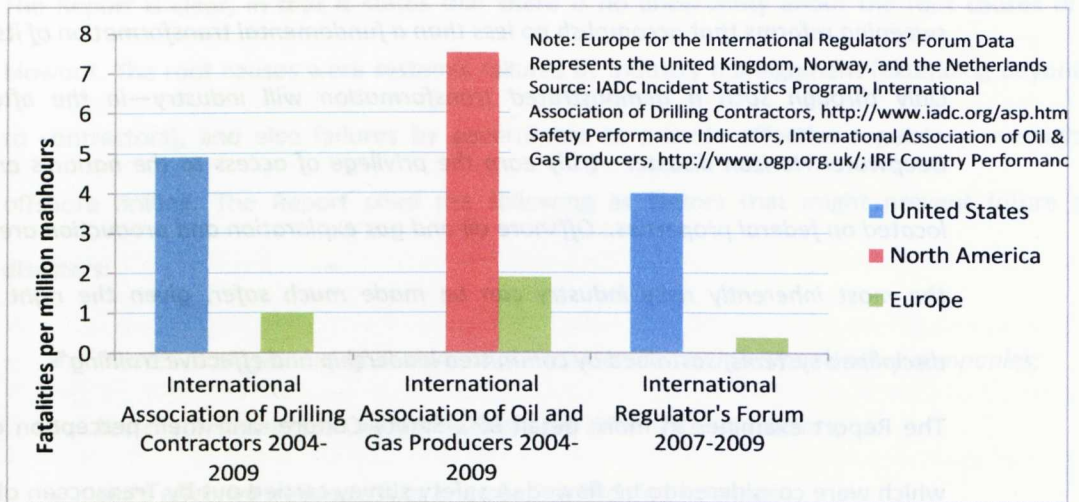
Main Contractors

Halliburton is one of the world's largest oil and gas industry service providers, which in 2009, was valued at \$1.7 billion. It has significant resources and expertise in cementing operations, and was contracted by BP to cement the Macondo well. Yet, despite the quality of the cement job on the Macondo well failing Halliburton's own tests, BP, Haliburton and Transocean management still allowed work to continue on the well [352].

Global operations and risk

The Report states that, *"From 2004 to 2009, fatalities in the offshore oil and gas industry were more than four times higher per person hours worked in U.S. waters than in European waters, even though many of the same companies work in both venues (Figure 27)".* It continues, *"This striking statistical discrepancy reinforces the view that the problem is not an inherent trait of the business itself, but rather depends on the differing cultures and regulatory systems under which members of the industry operate"*.

Figure 27 Comparisons of Fatalities with U.S. Performance



The role of Non-Governmental Organisations (NGOs)

The American Petroleum Institute (API) is the only national trade association that represents all aspects of America's oil and natural gas industry. In this context it has a potential conflict of interests, since it acts as the industry's principal lobbyist and public policy advocate. Since safety rules would make oil and gas industry operations potentially more costly, API regularly resists agency rulemakings that government regulators believe would make those operations safer, such as the Safety and Environmental Management System (SEMS); although the SEMS is widely applied elsewhere in the world, API prefers voluntary recommended safety practices instead [353].

Learning from Accidents: Exxon, Shell, and Bhopal

In order to emphasize the failure to learn lessons from previous disasters, the Deepwater Horizon Investigation Report cites the *Exxon Valdez* disaster, a Shell incident in 1999, in which two men died on a North Sea installation, the Texas City disaster (2005), and the disastrous 1984 chemical leak in Bhopal, India, and states, "Of course, in drawing lessons from prior accidents, it is essential

that they be projected beyond the particular circumstances of the accident at hand, to guide present and future performance, lest government regulators and industry leaders make the classic mistake of preparing to fight the last war."

While the Report acknowledges the needs for regulatory monitoring and intervention, where necessary, it recognises the need for self-regulation, on the basis that, those who create the risks should be responsible for managing them. However, based on the history of previous disasters, unless there is a change in the industry that addresses the combination of a lax regulator, profit maximisation by the private sector, poor safety culture and the failure of the industry to robustly capture lessons learnt from previous disasters, then future disasters are likely.

Report Recommendations

To accomplish goals of creating a new approach to risk assessment and management the following three sets of recommendations, relevant to safety performance, were made, and are summarised as:

A1: To supplement the risk-management programme with prescriptive safety and pollution-prevention standards that are at least as rigorous as the leasing terms and regulatory requirements in peer oil-producing nations;

A2: To develop a proactive, risk-based performance approach specific to individual facilities, operations and environments, similar to the 'safety case' approach in the North Sea;

A3: To work with interested parties, identify the standards that best protect offshore workers and the environment, and initiate new standards, reviewed every 5 years, and produce revisions to fill gaps and correct deficiencies;

A4/A5: To create an independent enforcement agency, with adequate resources, to oversee all aspects of offshore drilling safety (operational and occupational), as well as the structural and

operational integrity of all offshore energy production facilities, including both oil and gas production and renewable energy production;

D4: To design wells that demonstrate that:

- Well components, including blowout preventer stacks, are equipped with sensors or other tools to obtain accurate diagnostic information—for example, regarding pressures and the position of blowout preventer rams.
- Wells are designed to mitigate risks to well integrity during post-blowout containment efforts;

F3: To enhance auditing and evaluation of the risk of offshore drilling activities by individual participants (operator, driller, and other service companies);

G1: To increase and maintain congressional awareness of the risks of offshore drilling; and

G2: That Congress should enact legislation creating a mechanism for offshore oil and gas operators to provide ongoing and regular funding of the agencies regulating offshore oil and gas development [172].

5.7 Position of the UK Regulations regarding Deep Water Drilling

Following the Deepwater Horizon accident, a UK Department for Energy and Climate Change (DECC) Committee raised serious doubts about whether the UK oil industry could tackle a deep water blowout in the North Sea. The Government's response was that existing rules were adequate. The Government had already taken a number of actions, including increasing the number of inspectors and inspections to mobile drilling rigs to bolster the robust UK regulatory regime [193].

5.8 Comparison of key findings from the case study investigation reports

Analysis of the four major accidents, in general, excludes immediate causes, i.e. those events that led directly to the major accidents, since immediate causes are likely to be relatively unique to each event. Therefore the analysis focuses on the root causes, since they are generally embedded in an OH&S-MS, and therefore may have elements of commonality across all accidents which can be used to help prevent future accidents. Consequently the comparison of case study key investigation findings provides a timeline to judge whether there have been common failures that should have helped prevent future disasters, and whether the industry had sufficient time to be able to react to them. However, one of the problems encountered when comparing the findings from the four case study investigation reports is that the investigation reports are not presented in a consistent way. This makes extracting immediate and root causes for comparison difficult. Also, in some cases different terms are used that may relate to either category, e.g. the use of terms such as underlying causes and contributory causes, or none of the above terms are used.

Comparisons are listed in Table 15 below, and are benchmarked against the provisions contained in HSG65. So independently of major accidents, and the associated lessons learnt, the provisions within HSG65, if effectively implemented, should also provide the means to prevent accidents. It should be noted that Piper Alpha preceded the introduction of HSG65 by approximately three years.

Table 15 Comparison of key findings from the case study investigation reports

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater (offshore)	2010 Horizon	HSG 65 Successful health and safety management
1	The safety management system should set out the safety objectives, the system by which these objectives are to be achieved, the performance standards which are to be met and the means by which adherence to these standards is to be monitored.	BP Group Board or senior executives Did not provide effective oversight of the company's safety culture and major accident prevention programs.	The Board of HOSL did not grasp its COMAH responsibilities. The loss of secondary and tertiary containment at both the HOSL and BPA sites can also be traced back to failings in the respective safety management systems. The bunding failures found at Buncefield resulted from several underlying root causes within the safety management system.	The most significant failure at Macondo—and the clear root cause of the blowout—was a failure of industry management. BP ignored factors such as fatigue, long shifts, and the company's poor safety culture.		Effective health and safety policies set a clear direction for the organisation to follow. Organisations need to promote a positive safety culture, and secure the implementation and continued development of the [safety] policy.
2	The safety case should demonstrate that the potential hazards of the installation and the risk to people have been identified and appropriate controls provided.	Senior Executives: Inadequately addressed controlling major hazard risk. Personal safety was measured, and rewarded, and the primary focus, but the same emphasis was not put on improving process safety performance.	The HOSL joint venture did not effectively manage major hazards. It appeared more of an inconvenience for the financial management of the venture. The safety report was therefore a vehicle in which HOSL could, and indeed did, set out their principles for managing the major hazard aspects of their operations. However, what was set out in the document and the safety management systems did not reflect what actually went on at the site.	Missing has been any systematic updating of the risk assessment and risk management tools used as the basis for regulation.		There is a planned and systematic approach to implementing health and safety policy that minimises risks. Risk assessment methods are used to decide priorities and to set objectives for eliminating hazards and reducing risk.

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater (offshore)	Horizon 2010	HSG 65 Successful health and safety management
3	The acceptance standards for risk should be set before the submission of the safety case. Standards should be set by reference to the ALARP principle.	Senior Executives: Personal safety was measured, and rewarded, and the primary focus, but the same emphasis was not put on improving process safety performance.	Risk assessments did not consider the implications of more than one tank being on fire. They did not assess the impact of the release of large volumes of fuel and firewater as might occur following explosion and/or escalation – scenarios known to the site operator before the incident. The risk assessments also failed to consider that bunds might fail structurally (eg due to impact of fire) as well as their capacity being exceeded.	Three major companies failed to apply rigorous process safety measures to their drilling operations in the Gulf of Mexico: Halliburton and Transocean, which service drilling operations throughout the Gulf, along with BP, underscoring the systemic nature of the offshore industry's problems.		Performance is measured against agreed standards to reveal when and where improvement is needed (covers plants, processes and people).
4	The regulatory body should be required to regularly audit to verify that the safety management system is satisfactory.	Senior Executives: Ineffectively ensured that the safety implications of major organizational, personnel, and policy changes were evaluated.	To manage the pressures, staff were working a considerable amount of overtime which was costly. To overcome this management tried to recruit a further supervisor. However, when a new member of staff was recruited it was immediately counterbalanced by the resignation of another.	BP did not have in place (or did not enforce) any policy that would have required personnel to call back to shore for a second opinion about confusing data.		An effective management structure and arrangement are in place for delivering the [safety] policy.
5		Senior Executives: Did not provide adequate resources to prevent major accidents; budget cuts impaired process safety performance at the Texas City refinery.	The Judge commented that cost cutting <i>per se</i> was not put forward as a major feature of the prosecution case, but the failings had more to do with slackness, inefficiency and a more-or-less complacent approach to matters of safety.	Decision making processes at Macondo did not adequately ensure that personnel fully considered the risks created by time- and money-saving decisions.		Effective health and safety policies contribute to business performance by ensuring a systematic approach to the identification of risks and the allocation of resources to control them.

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater (offshore)	Horizon 2010	HSG 65 Successful health and safety management
6		BP Managers did not: Create an effective reporting and learning culture; reporting bad news was not encouraged. Incidents were often ineffectively investigated and appropriate corrective actions not taken.	Bund failures were not treated as 'near misses'. This would have triggered an investigation of the root cause of those failures and enabled corrective actions to be implemented.	Transocean failed to adequately communicate lessons from an earlier near-miss to its crew. Historically there has been no legal requirement that industry track or report instances of uncontrolled hydrocarbon releases or "near misses" - both indicators that could point to a heightened potential for serious accidents.	Effective reporting provides opportunities for an organisation to check performance, learn from mistakes, and improve the health and safety management system and risk control.	
7	Regarding modifications to installations or their equipment or procedures, the operator should, before putting the modification into effect, ascertain what impact it would have on the safety case.	BP Managers did not: Ensure that supervisors and management modelled and enforced use of up-to-date plant policies and procedures.	Management of change procedures were not adequately applied to bund projects. Changes during design and construction were not reviewed in terms of impact on the ability of the bund to retain liquids during an incident.	BP's management process did not adequately identify or address risks created by late changes to well design and procedures. There is no evidence that changes went through any sort of formal risk assessment or management of change process.	Control arrangements are very important and should form part of the organisation's policies. A key part of the process of establishing control is draw up written systems, rules or procedures to clarify the way jobs or tasks should be done to achieve the desired results.	
8	The safety management system and that of the installation are adequate to ensure the design and operation of its equipment are safe.	BP Managers did not: Incorporate good practice design in the operation of the ISOM unit.	The bunding at Buncefield had many flaws, which caused large volumes of fuel, foam and firefighting water to leak out of the bunds. Bunds were not fire impermeable and not fire resistant. The bunding was unable to handle the large volumes of firewater involved in the incident. Systems for control of contractors (including those designing and constructing bunds) did not ensure bunding work was in accordance with good practice.	There is a need for a more robust well design as BP government could not get accurate pressure readings, which in turn hampered their ability to estimate the oil flow rate, undertake reservoir modeling, and plan for source control operations. In addition, the blowout preventer lacked a means of indicating whether and to what extent its rams and annular preventers had closed.	Key tasks for managers and implementers of policy is keep up to date with changes in health and safety legislation, standards and good practice and with management practices relevant to the organisation.	

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater (offshore)	2010 Horizon	HSG 65 Successful health and safety management
9		BP Managers did not: Ensure that operators were supervised and supported by experienced, technically trained personnel during unit start-up, an especially hazardous phase of operation.	The contract with Motherwell was clearly a safety critical arrangement and the competence and training of Motherwell staff working with critical equipment should have been evaluated. There appears to have been little if anything done, although this was identified by auditors.	Ultimately, MMS was unable to ensure that its staffing capabilities and competencies kept pace with the changing risks and volume of offshore activity.		Managers, by example and discipline, are uniquely placed to influence how well organisations achieve health and safety objectives and what standards of performance are maintained. They can plan, direct, help, train, coach and guide staff to develop individual competence.
10		BP Managers did not: Effectively incorporate human factor considerations in their training, staffing, and work schedule for operations personnel.	Management failed to recognise unacceptable working pressures, although when the Operations Manager offered his resignation shortly before the incident because of the pressurised environment this should have confirmed that all was not well.	BP, Transocean, and Halliburton failed to communicate adequately.		The design of all workplace precautions should consider human factors. In successful organisations the design of precautions is fully integrated into plant and work design procedures so that specifications simultaneously satisfy output, quality, and health and safety requirements. Employee involvement encourages solutions which are relevant and practical for those who have to implement them.

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater Horizon (offshore)	HSG 65 Successful health and safety management
11	The operator should be required to satisfy itself by means of regular audits that the safety management system is being adhered to.	Contributing causes: BP Managers: Lacked an effective mechanical integrity program to maintain instruments and process equipment. For example, malfunctioning instruments and equipment were not repaired prior to start-up.	The investigation revealed that fault logging at HOSL, in relation to key equipment and working practices, was inadequate. The shift system of working led to problems with no proper overview of what was going wrong and why.	The House Committee on Education and Labour and the Senate Committee on Health, Education, Labour, and Pensions appeared to focus on process safety—the vital approach identified by this Commission's investigation that encompasses procedures for minimizing adverse events such as effective hazard analysis management of risk, communication, and auditing.	"Technical" audits may be necessary to verify the continued effectiveness of complex workplace precautions, eg process plant integrity and control systems and wherever the containment of hazardous materials is important (eg where flammables or toxics are used), maintenance and process change procedures are necessary to ensure plant integrity.
12		BP Managers: Did not have an effective vehicle traffic policy to control vehicle traffic into hazardous process areas or to establish safe distances from process unit boundaries.	There was no tank filling system worth its name. Considering that this was the single most important process control system to prevent loss of containment of fuel, this was a serious management failure in the control of a major accident hazard.	There was a failure to contain hydrocarbon pressures in the well. Three things could have contained those pressures: the cement at the bottom of the well, the mud in the well and in the riser, and the blowout preventer. But mistakes and failures to appreciate risk compromised each of those potential barriers, steadily depriving the rig crew of safeguards until the blowout was inevitable and, at the very end, uncontrollable.	A key feature of an effective health and safety policy is to examine all unsafe events and the behaviours which give rise to them. This is a way of controlling risk and measuring performance.

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater (offshore)	Horizon 2010	HSG 65 Successful health and safety management
13		BP Managers: Ineffectively implemented their Pre Start-up Safety Review (PSSR) policy; nonessential personnel were not removed from areas in and around process units during the hazardous unit start-up.	There was no periodic review of the bunds' characteristics compared to up-to-date standards and guidance. (This is one purpose of safety reports).	Two April foam stability tests further illuminate problems with Halliburton's cement design process. Like the two February tests, the first April test indicated the slurry was unstable. This should have prompted Halliburton to review the Macondo slurry design immediately, especially given how little time remained before the cement was to be pumped. There is no indication that Halliburton ever conducted such a review		Auditing and review are the final steps in the health and safety management control cycle. They constitute the 'feedback loop' which enables an organisation to reinforce, maintain and develop its ability to reduce risks to the fullest extent and to ensure the continued effectiveness of the health and safety management system.
14	The evidence demonstrates a serious failure on the part of the Den (offshore safety regulator at the time of the disaster) to address regulatory requirements for dealing with the major hazards.	OSHA's capability to inspect highly hazardous facilities and to enforce process safety regulations is insufficient; very few comprehensive process safety inspections were conducted prior to the ISOM incident, and only a limited number of OSHA inspectors have the specialized training and experience needed to perform these complex examinations.	HSE is not routinely consulted in the critical early stages of regional development planning, and when it is consulted is not always able to respond adequately.	Government also failed to provide the oversight necessary to prevent these lapses in judgment and management by private industry.		

No.	Piper Alpha 1988 (offshore)	BP Texas City 2005 (onshore)	Buncefield 2005 (onshore)	Deepwater Horizon (offshore)	2010 Horizon	HSG 65 Successful health and safety management
15		BP site had a Total Reportable Incident Rate (TRIR) that was a third of the industry average and therefore the site was not targeted by OSHA		The Deepwater Horizon investigation stated that BP's safety record in the GoM was reportedly excellent and this influenced their decision making. The implication is that historical safety data is an accurate indicator of actual safety performance, and is also a good predictor of future performance		
16	In 1998 the Piper Alpha Inquiry recommended that the regulator maintain a hydrocarbon leak database (as the industry was too focused on occupational rather than process safety).	The focus was primarily on personal safety rather than process safety.	Process safety controls on safety critical operations were not maintained to the highest standard.	It was clear that BP's focus had been about individual worker occupational safety and not on process safety.		

5.9 Summary

5.9.1 OH&S-MS Related Items

While Piper Alpha, Texas City (2005) and Deepwater Horizon have, or will, cause some step changes in the way the industry manages safety, the comparison of causes, and using HSG65 as a benchmark for OH&S-MS implementation (Table 15) suggests that while lessons have been learnt during each investigation, the industry has failed to robustly capture these lessons to prevent future disasters. The findings from each investigation have been relatively unambiguous, and with the exception of the two disasters in 2005, there has been ample time for the industry to modify their OH&S-MS in order to address both the conclusions and recommendations from these reports.

Repeated themes that are derived from Table 15 include:

- With the exception of Occidental (owners of the Piper Alpha), the companies associated with the disasters, who are reasonably representative of the global industry, have failed to establish an effective OH&S-MS.
- Safety culture has been poor and this is probably reflected in the majority of findings, but in particular that major hazards have not been adequately managed through suitable and sufficient risk assessment.
- Resources, communications and organisational factors (all essential elements of an effective OH&S-MS) have systematically failed, or been largely ineffective.
- Incidents, including near-miss reporting, have not provided opportunities to learn from errors before they contributed to more serious incidents.
- Management of change has been inadequate and there has been a failure to recognise and apply good or best practice to the various elements of the OH&S-MS.
- Human factors were not properly considered and integrated into the system of work, and the systems for ensuring design, operating and asset integrity has been poor.

- Injury based incident performance was, inappropriately, seen as a good indicator of future performance and the industry has focused on occupational safety rather than process safety. Process safety failures are more likely to be a precursor to a major accident.
- A significant theme for all four disasters is regulatory oversight. Lack of regulatory intervention and enforcement may have been regarded by the industry as an indirect acceptance of their management of safety. However, all investigations have demonstrated that the regulator has been ineffective.

5.9.2 Non Specific OH&S-MS Items

Design

Of the 106 recommendations made by the Piper Alpha Inquiry, 38 relate to design, e.g. control of the process, hydrocarbon inventory, risers and pipelines, fire and gas detection, fire and explosion protection and temporary safe refuge, etc. Some of these design recommendations addressed the features of inherent safety, e.g. minimising the hydrocarbon inventory by installing pipeline safety valves, but failed to fully explore all the principles of inherently safe design. However, this should have given the industry a strong signal that inherently safe design should be incorporated into management systems. For example, this could have averted the 2005 Texas City disaster had proposals to make the process inherently safer been accepted and implemented by BP management.

Cost

A weakness with the Piper Alpha Inquiry is that it failed to understand why pipelines feeding flammable product to the Piper Alpha had not been shut down earlier. Given the wealth of information, about the events unfolding on the Piper Alpha, that was available to the OIMs on adjacent installations responsible for these pipelines, it might be concluded that the pressure to

maintain production, and therefore generate revenue, was so intense that it outweighed the overwhelming evidence that the pipelines had to be shut down. This relates to the safety culture within the organisation, and perhaps within the industry, at that time. Had this element been explored in more detail, in the Inquiry, then the decisions taken at Texas City not to install process safety measures, and the flawed decision-making drilling the Macondo well may have been avoided.

6. DATABASE ANALYSIS

6.1 Introduction

The purpose of this Chapter is to present the findings from the deductive and inductive research methodologies in a systematic, objective and unbiased format so that analysis, discussion and conclusions can be established.

Deductive research was carried out in with four objectives in mind:

- To determine the number and trend of major accidents or disasters in the oil and gas industry in order to establish whether they could be classified as 'random' events, or if a discernible trend existed;
- to examine the magnitude of the economic losses incurred by oil and gas companies due to major accidents or disasters, in order to establish whether this could affect their ability to meet financial and safety performance requirements;
- to determine historical safety performance with regard to levels of performance, trends in terms of continuous improvement and therefore sustainability of performance; and
- to assess UK regulator enforcement through their use of Prohibition and Improvement Notices to the oil and gas industry, in order to identify levels and trends of enforcement in relation to safety performance.

6.2 Major accidents or disasters

Given the various definitions and labels associated with major accidents, limited access to authoritative databases, and the variability of search criteria in available and relevant databases, the results for major accidents or disasters can be highly variable and inconsistent. Consequently, much of the information obtained in this part of the research was derived from a variety of sources and has been validated where possible.

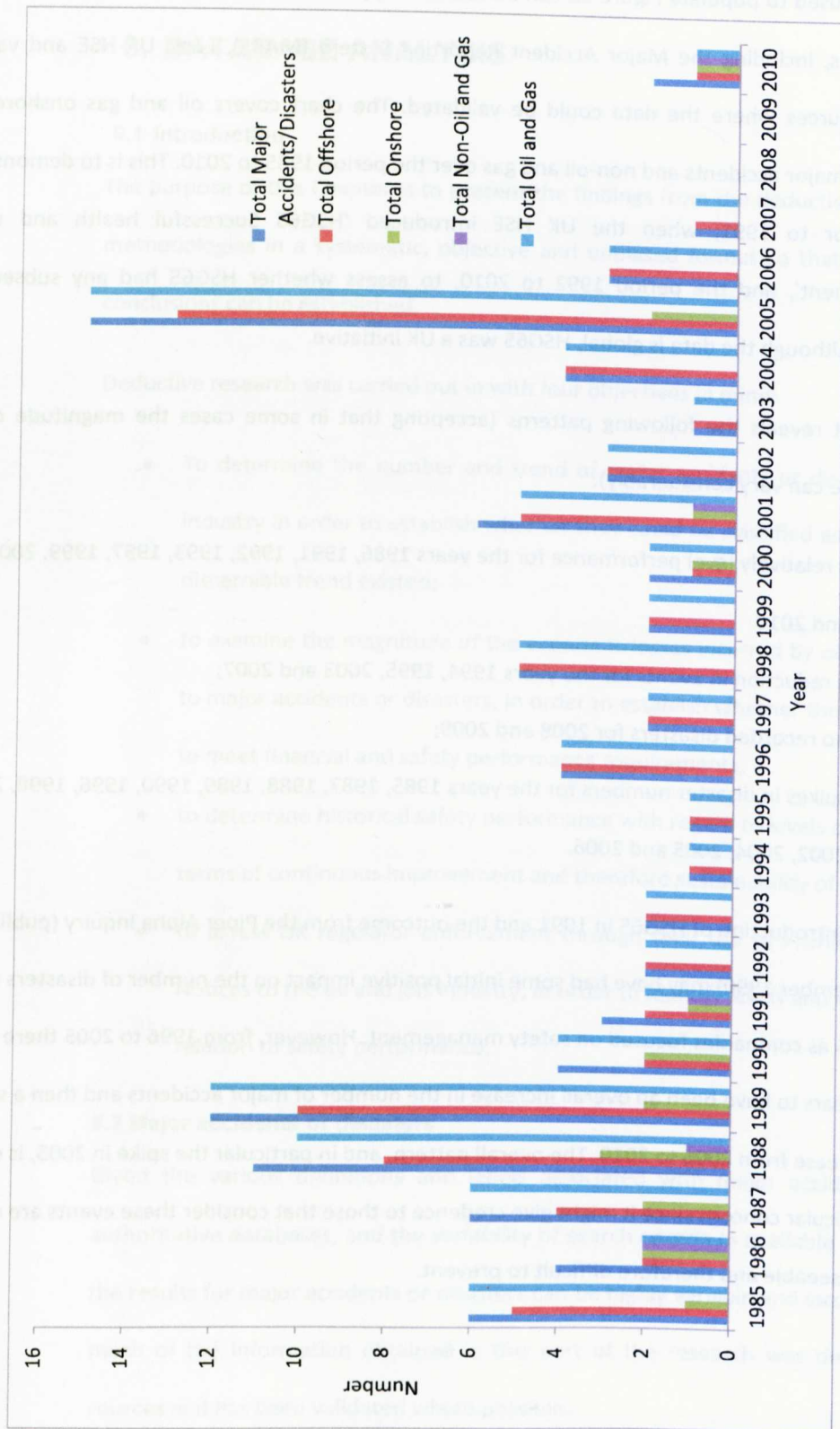
The data used to populate Figure 28 can be found in Appendix B. This was created from a variety of sources, including the Major Accident Reporting System (MARS), Lees, UK HSE and various online sources where the data could be validated. The chart covers oil and gas onshore and offshore major accidents and non-oil and gas over the period 1985 to 2010. This is to demonstrate data prior to 1991, when the UK HSE introduced 'HSG65 Successful health and safety management', and the period 1992 to 2010, to assess whether HSG65 had any subsequent impact. Although the data is global, HSG65 was a UK initiative.

The chart reveals the following patterns (accepting that in some cases the magnitude of the difference can vary considerably):

- a) a relatively level performance for the years 1986, 1991, 1992, 1993, 1997, 1999, 2000, and 2010
- b) a reduction in events for the years 1994, 1995, 2003 and 2007;
- c) no recorded disasters for 2008 and 2009;
- d) spikes in disaster numbers for the years 1985, 1987, 1988, 1989, 1990, 1996, 1998, 2001, 2002, 2004, 2005 and 2006.

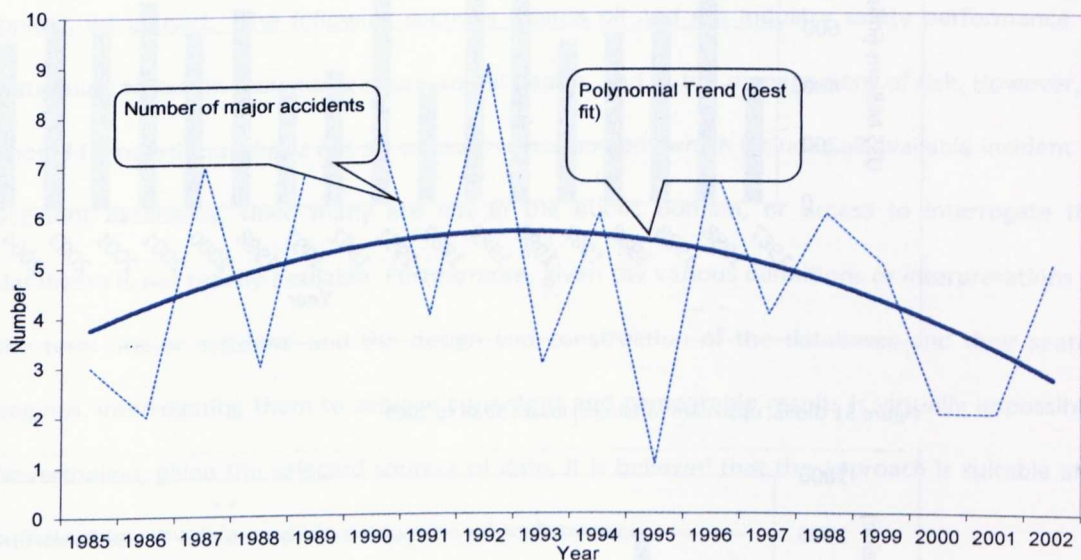
The introduction of HSG65 in 1991 and the outcome from the Piper Alpha Inquiry (published November 1990) may have had some initial positive impact on the number of disasters until 1995 as companies focused on safety management. However, from 1996 to 2005 there appears to have been an overall increase in the number of major accidents and then a sudden decrease from 2006 to 2010. The overall pattern, and in particular the spike in 2005, is of particular concern since it might give credence to those that consider these events are not foreseeable and therefore difficult to prevent.

Figure 28 Major Accidents or Disasters 1985 to 2010



The Major Accident Reporting System (MARS) data (Figure 29), shows that there are variations in annual performance, but given the relatively limited number of major accidents, the trend is significantly influenced by single events. The pattern of major accidents does illustrate the huge variation in numbers year-on-year, giving rise to the speculation that these events are 'random'. However, it is evident that major accidents, up to 2002, still occurred in the EC on a regular basis.

Figure 29 MARS Number of major accidents in the petrochemical industry per year of occurrence 1985 to 2002



6.3 Financial Losses

The economics associated with major accidents can have a significant impact on the reputational and financial status of a company, which could be used as an argument to secure greater investment in the prevention and mitigation of these events, as illustrated by the Deepwater Horizon disaster and its impact on BP. Prior to Deepwater Horizon in 2010, the industry suffered a number of major accidents and disasters, and the estimated financial losses incurred are illustrated in Figure 30 and Figure 31 below [354]. The charts show a pattern of highs and lows and, other than illustrating the variable costs to the industry over time, suggest that there are significant financial savings still to be made if major accidents can be prevented. This may give weight to the need to invest more in major accident prevention.

Figure 30 The overall 20 largest petrochemical losses 1987 to 2009

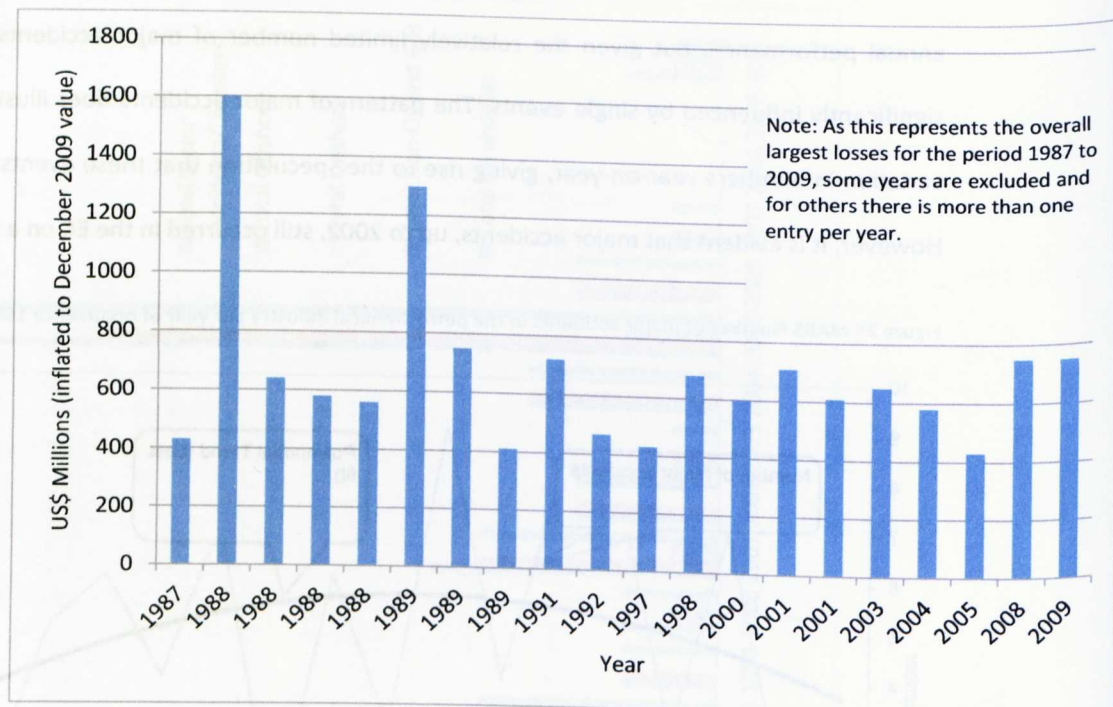


Figure 31 Global upstream (offshore) losses 1988 to 2009

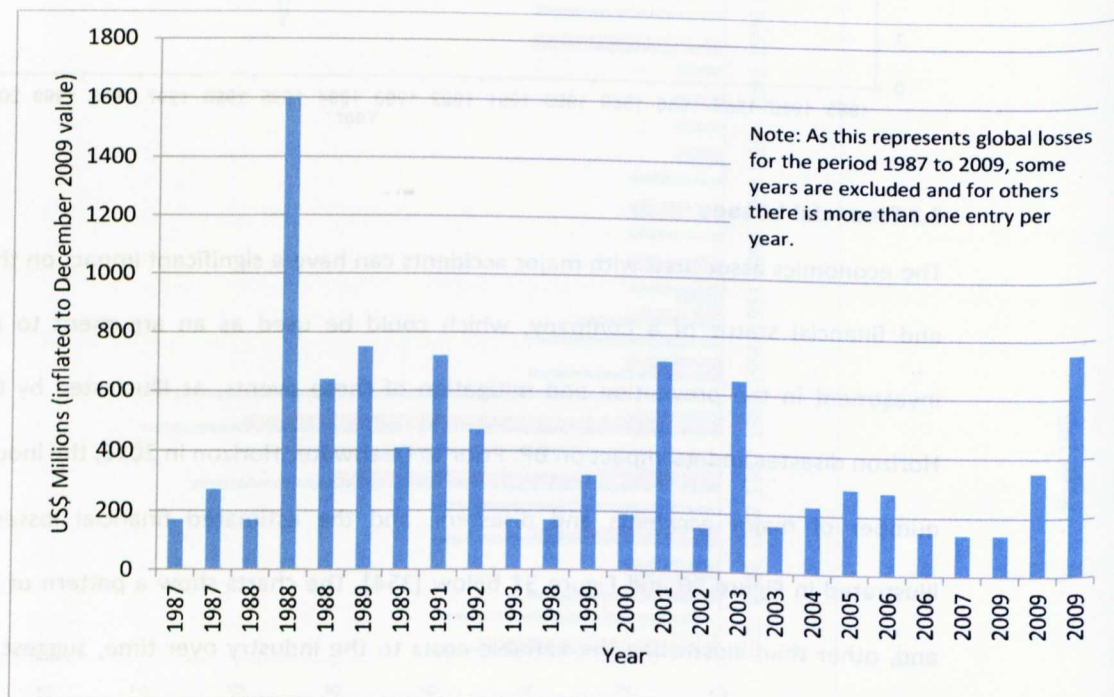


Figure 30 and Figure 31 exclude the losses associated with Deepwater Horizon. This data shows a relatively weak trend but is consistent with the random nature of disasters.

6.4 Safety Performance

The aim of this section is to investigate whether a range of published statistics on major accidents and other incidents can be used to assess the safety performance of the oil and gas industry. Statistics from the period from 1985 to 2010 from various publically-available sources, described below, were used. The following sections discuss oil and gas industry safety performance to determine trends in preventing injury and ill health, and in the management of risk. However, it should be noted that this is not an exhaustive assessment which includes all available incident or accident databases, since many are not in the public domain, or access to interrogate the databases is not readily available. Furthermore, given the various definitions or interpretations of the term 'major accident' and the design and construction of the databases and their search engines, interrogating them to achieve consistent and comparable results is virtually impossible. Nevertheless, given the selected sources of data, it is believed that the approach is suitable and sufficient to provide a credible evaluation of performance.

6.4.1 Results and Discussion

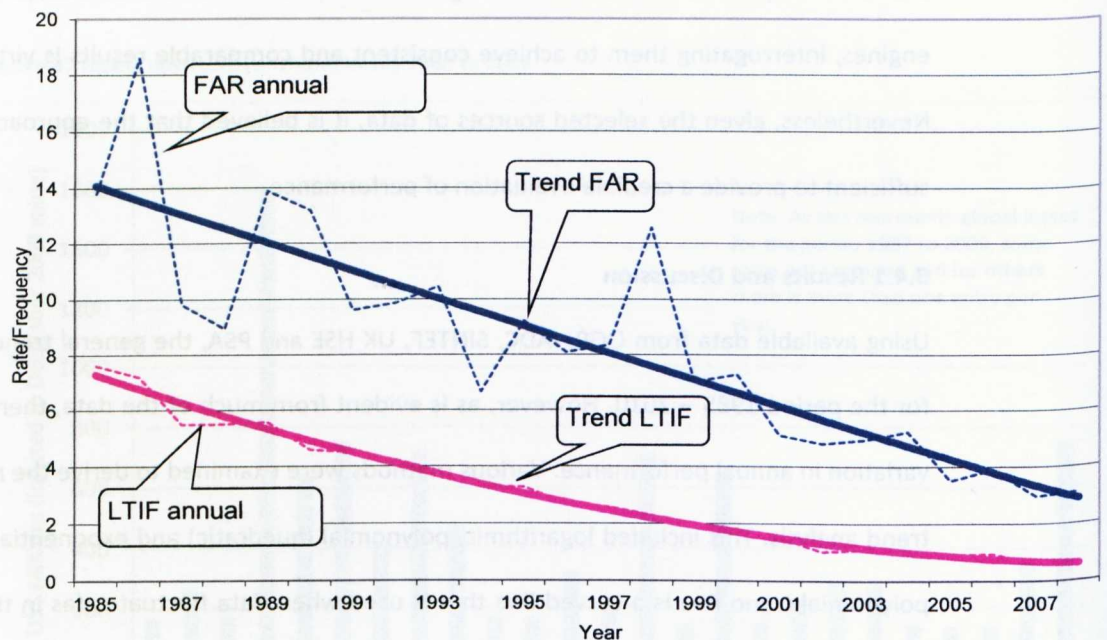
Using available data from OGP, IADC, SINTEF, UK HSE and PSA, the general trends were assessed for the period 1985 – 2010. However, as is evident from much of the data, there is considerable variation in annual performance. Various methods were examined to derive the most appropriate trend analysis. This included logarithmic, polynomial (quadratic) and exponential trend lines. The polynomial trend line is a curved line that is used when data fluctuates (as in the present case), and therefore this was applied to this analysis. A trend line is most reliable when its R-squared value is at or near 1. Polynomial trend lines were confirmed as the best fit for the data. Describing such trends with an appropriate polynomial is complicated by the fact that there are so many possible parameters. However, it is appropriate, in this analysis, to find a simple polynomial of low

degree that follows the general trend in the data. Such a polynomial may pass above or below many of the data points, but still accurately describe the data as a whole. This is the method of parametric curve fitting. While there are a variety of KPIs used in the industry for injury-based data, this analysis focuses on FAR and LTIF since, based on 'accident theory' (see Analysis of Performance below), both KPIs are considered to provide suitable indicators of overall accident trends.

6.4.2 Trends based on injurious outcomes

Figure 32 below shows the performance of OGP members for FAR and LTIF. Rounding up has resulted in some relatively minor differences between these results and those in the OGP Reports.

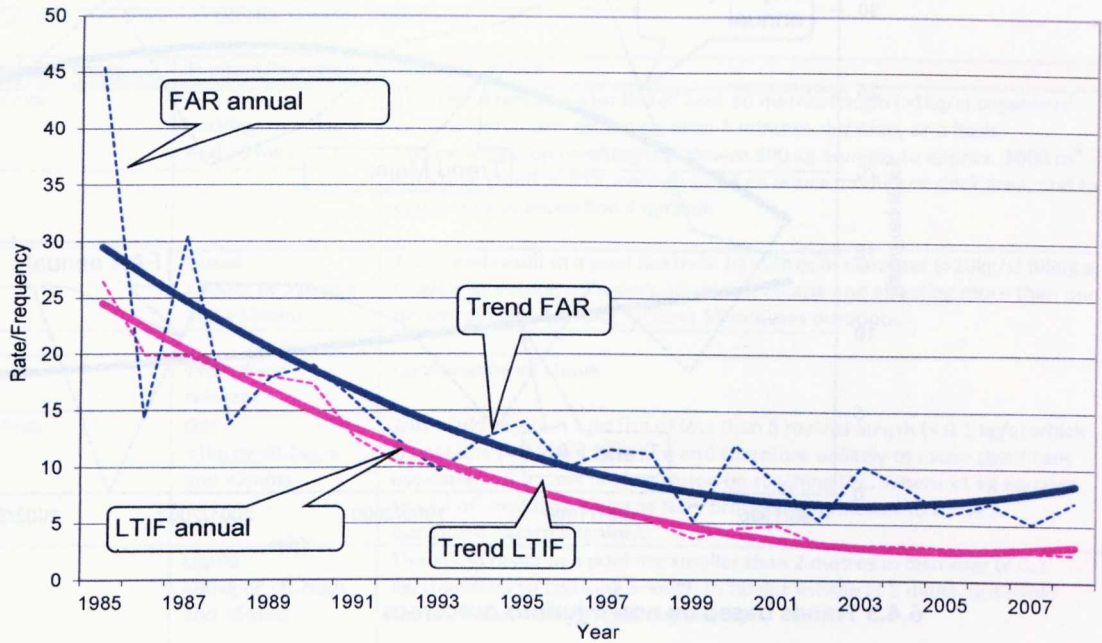
Figure 32 OGP Polynomial Trends for FAR and LTIF from 1985 to 2009



There are variations in annual performance, particularly for FAR, although trends for both FAR and LTIF suggests a continuous improvement in performance, with a downward trend in incidents.

Figure 33 shows the FAR and LTIF performance of IADC members who provided data.

Figure 33 IADC Polynomial Trends for FAR and LTIF from 1985 to 2009

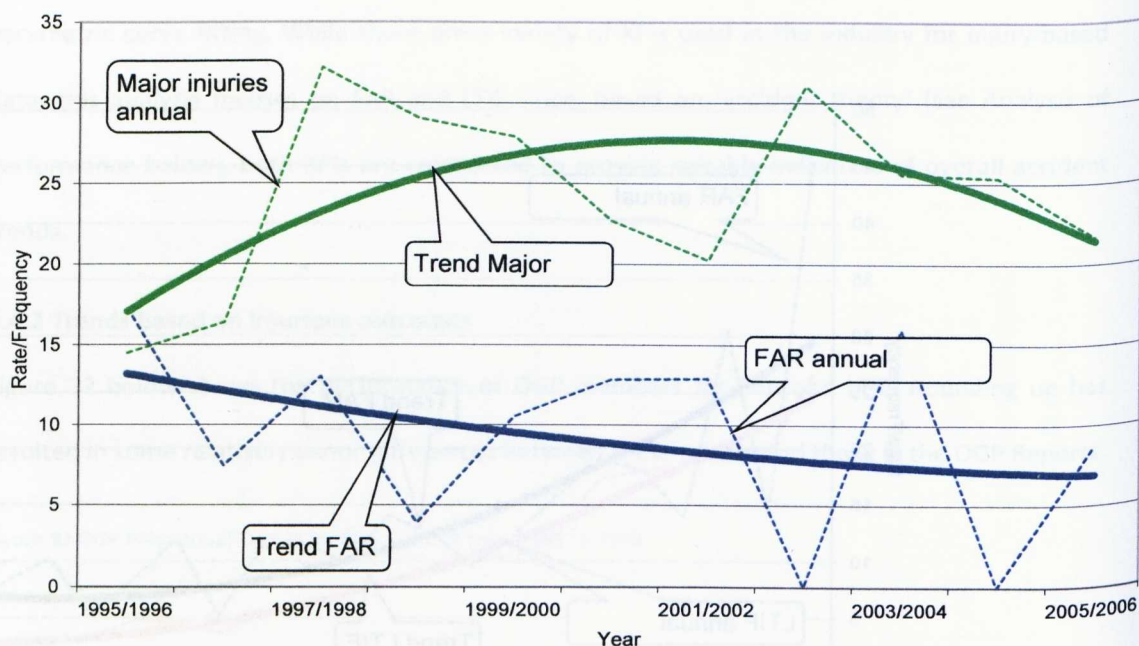


Again, there are variations in annual performance, particularly for FAR. While the trend in LTIF implies a continuous improvement in performance, the trend in FAR seems to have reached a plateau around 2000 – 2002, and then from 2003 shows an increasing FAR, representing deteriorating performance. These data also demonstrate the first signs that the incident rates are levelling off after a period of decline.

The injurious safety performance in the North Sea, as compiled by the UK HSE (Figure 34) also shows variations in annual performance, for both FAR and Major Injury Rate.

While the trend in FAR suggests a continuous improvement in performance, the trend in Major Injury Rate increases from the year 1995 to 2001/2002, when it reaches a maximum and then starts to decline.

Figure 34 UK HSE Polynomial Trends for Offshore FAR and Major Injuries from 1995 to 2010



6.4.3 Trends based on non-injurious outcomes

Typical major hazards on offshore installations include hydrocarbon and toxic releases from risers, and pipeline and process leaks; transport accidents (e.g. helicopter crashes and ship collisions), and structural collapse. These can result in fires and explosions, blowouts, loss of assets, and occupational accidents (multiple fatalities and serious injuries), etc.

Due to process characteristics such as high pressure, and high temperature in combination with relatively large inventories and the number of potential leak paths (e.g. valves, flanges, pumps, compressors, etc.), the hydrocarbon risk tends to dominate the overall offshore risk profile, as shown in Table 11. Hence, it is a particularly important indicator of safety performance when considered in relation to operational practices and preventative maintenance regimes designed to ensure asset integrity.

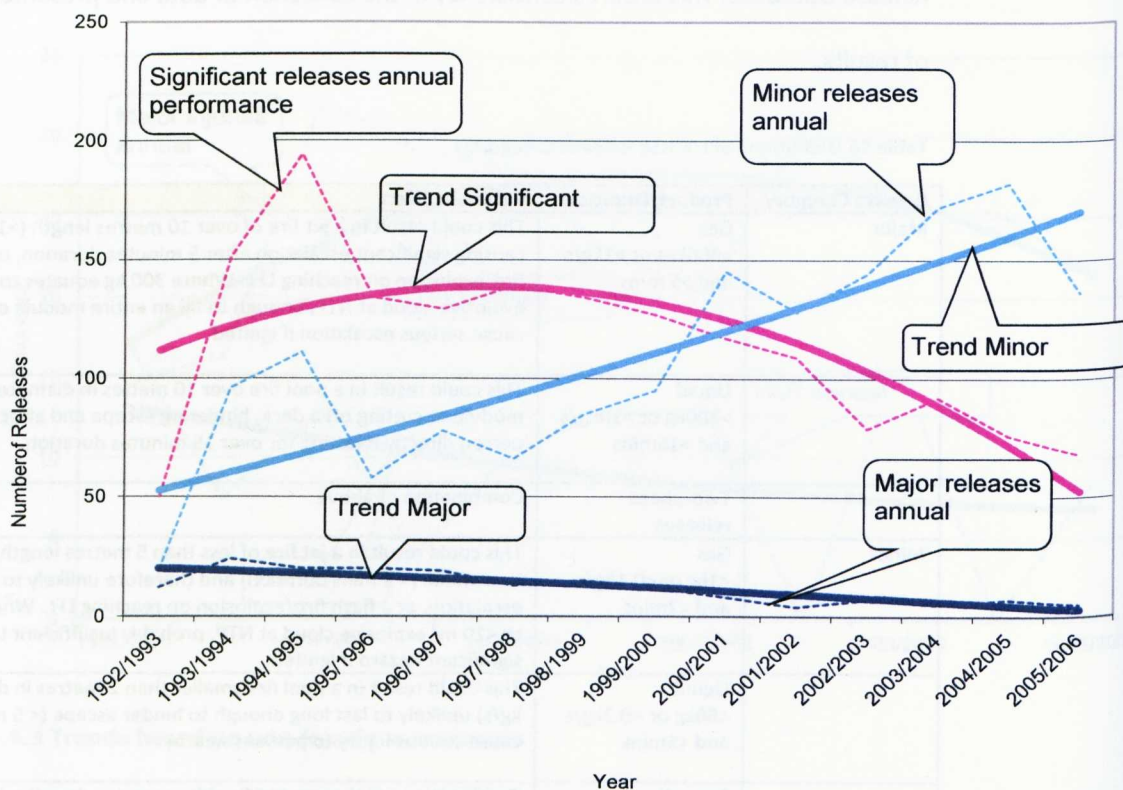
Table 16 shows the release categories and definitions used to populate the UK HSE Hydrocarbon Release Database. This ensures consistency in the collection of data and presentation and analysis of results.

Table 16 Definitions of UK HSE Release Categories

Release Category	Product/Duration	Potential Effect
Major	Gas >300kgs or >1kg/s and >5 mins	This could result in a jet fire of over 10 metres length (>1kg/s) capable of causing significant escalation after 5 minutes duration, or a flash fire/explosion on reaching LFL. Where 300 kg equates to approx. 3000 m ³ explosive cloud at NTP, enough to fill an entire module or deck area, and to cause serious escalation if ignited.
	Liquid >300kg or >10kg/s and >15mins	This could result in a pool fire over 10 metres in diameter (>10kg/s) filling a module or cutting off a deck, hindering escape and affecting more than one person directly if lasting for over 15 minutes duration.
	Two-phase releases	Combination of above
Minor	Gas <1kg or <0.1kg/s and <2mins	This could result in a jet fire of less than 5 metres length (< 0.1 kg/s) which is unstable (< 2 mins duration) and therefore unlikely to cause significant escalation, or a flash fire/explosion on reaching LFL. Where <1 kg equates to <10 m ³ explosive cloud at NTP, probably insufficient to cause a significant hazard if ignited.
	Liquid <60kg or <0.2kg/s and <5mins	This could result in a pool fire smaller than 2 metres in diameter (< 0.2 kg/s) unlikely to last long enough to hinder escape (< 5 mins), but could cause serious injury to persons nearby.
	Two-phase <1kg or <0.1kg/s	Combinations of the gas and liquids scenarios described above are possible, depending on gas-oil ratio involved.
Significant (between minor and major)	Gas	Capable of jet fires of 5 to 10 metres lasting for between 2-5 minutes, or release rates between 0.1 to 1.0 kg/s lasting 2-5 minutes giving explosive clouds of between 10 and 3000 m ³ in size.
	Liquid	Pool fires between 2 and 10 metres in diameter, lasting for between 5 and 15 minutes.
	Two-phase	Combinations of the gas and liquids scenarios described above are possible.

Figure 35 suggests that there have been reductions in the numbers of both major and significant hydrocarbon releases, although the reduction in minor releases is less pronounced.

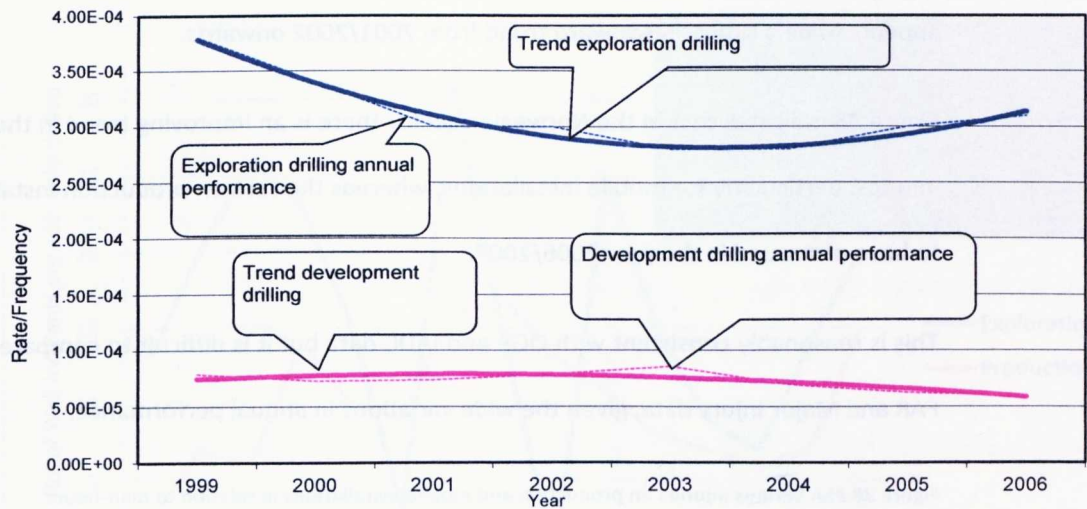
Figure 35 UK HSE Polynomial Trends for Offshore Hydrocarbon Releases



Similar to the UK HSE performance data, a further indicator of [drilling/well engineering] performance can be derived from the industry blowout statistics compiled by SINTEF.

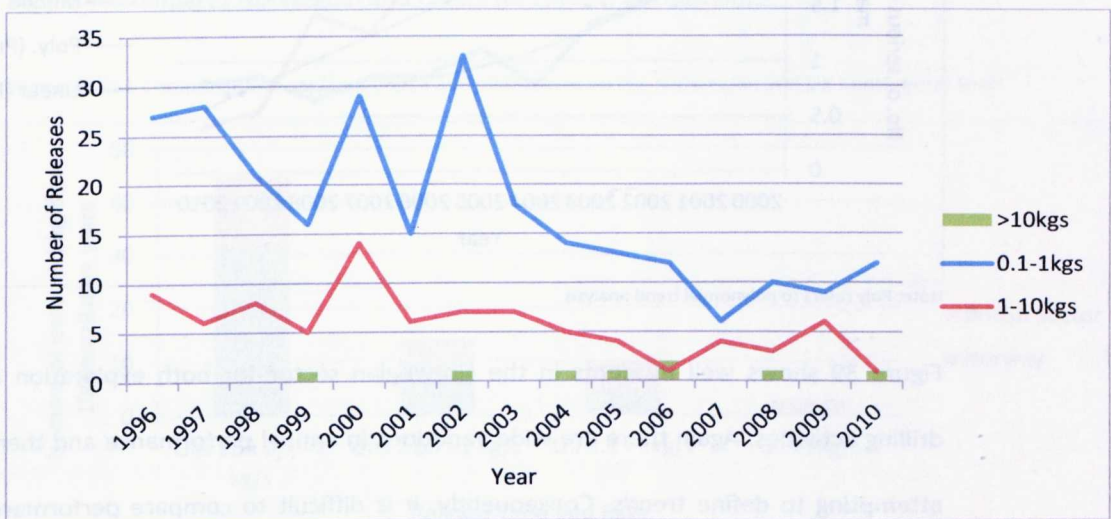
These trends (Figure 36) suggest that there has not been any overall significant improvement in development drilling blowout rate, and that the blowout rate during exploration drilling is increasing.

Figure 36 SINTEF Polynomial Trends for Exploration and Development Drilling Blowout Rates 1999 to 2006



PSA data from the Norwegian sector (Figure 37) shows there is a large variation in annual performance and therefore defining trends has limited value.

Figure 37 PSA Number of hydrocarbon leaks exceeding 0.1 kg s^{-1} (1996 – 2010)



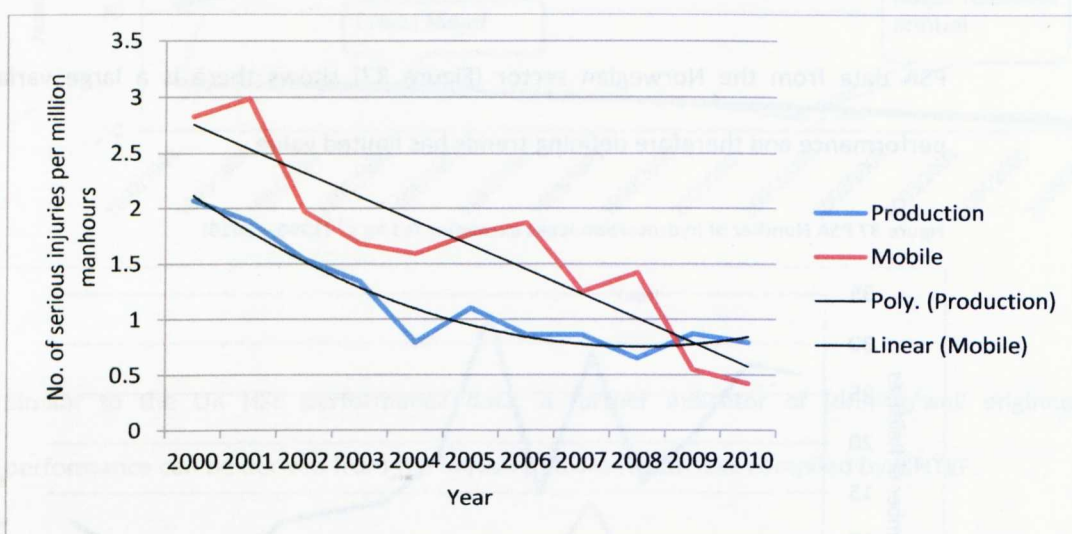
However, the overall trends seem to be improving after 2002, although there are still observed significant leaks greater than 10 kg s^{-1} , perhaps commensurate with the observed frequency of disasters, as major releases are often a precursor of major accidents in the oil and gas industry.

Similar to UK release data there are wide variations in performance, although in the UK there appears to be a similar downward trend from 2001/2002 onwards.

Figure 38 indicates that in the Norwegian sector there is an improving trend in the rate of serious injuries, particularly for mobile installations, whereas the rate on production installations appears to have plateaued in the year 2006/2007.

This is reasonably consistent with OGP and IADC data but it is difficult to compare against UK HSE FAR and Major Injury data, given the wide variations in annual performance.

Figure 38 PSA Serious injuries on production and mobile installations in relation to man-hours



Note: Poly refers to polynomial trend analysis

Figure 39 shows well incidents in the Norwegian sector for both exploration and production drilling activities. Again there are wide variations in annual performance and there is no value in attempting to define trends. Consequently, it is difficult to compare performance with SINTEF blowout data.

Figure 39 PSA Well incidents per 100 wells drilled

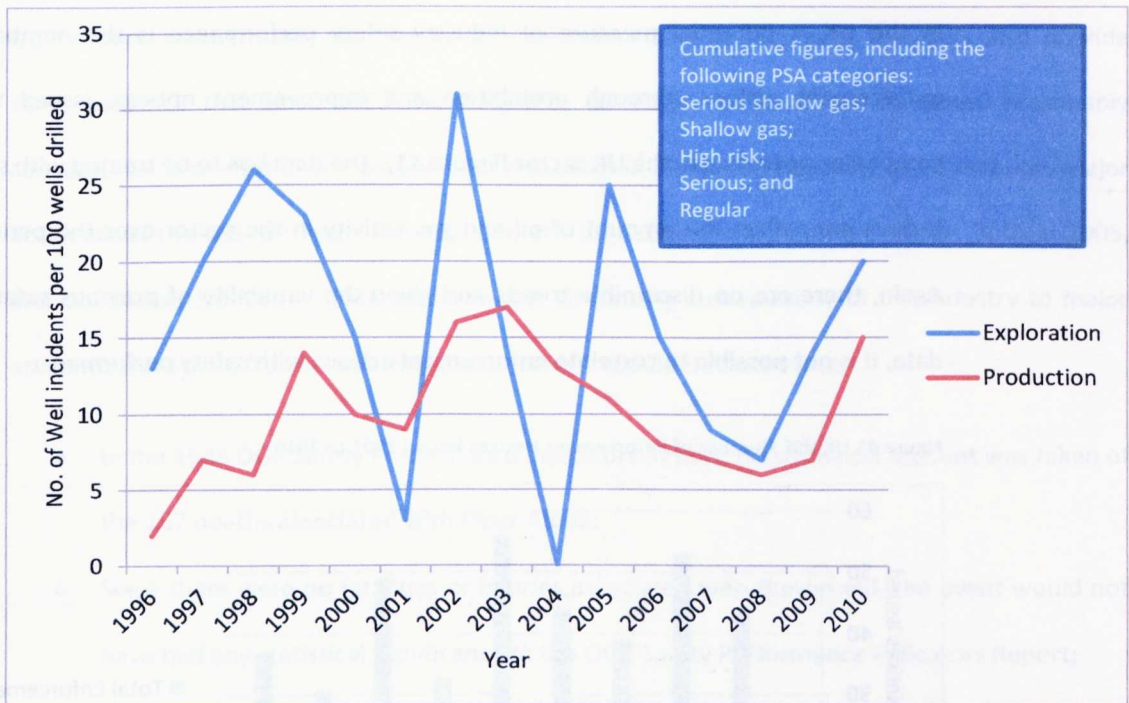
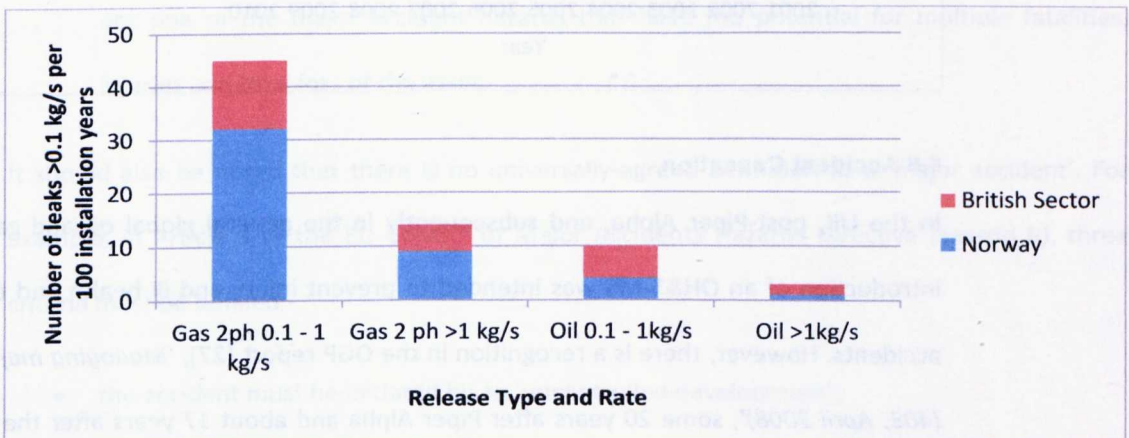


Figure 40 compares Norwegian and UK sector release performance.

Figure 40 PSA Comparison of gas/two-phase and oil releases on the Norwegian and UK Continental Shelf



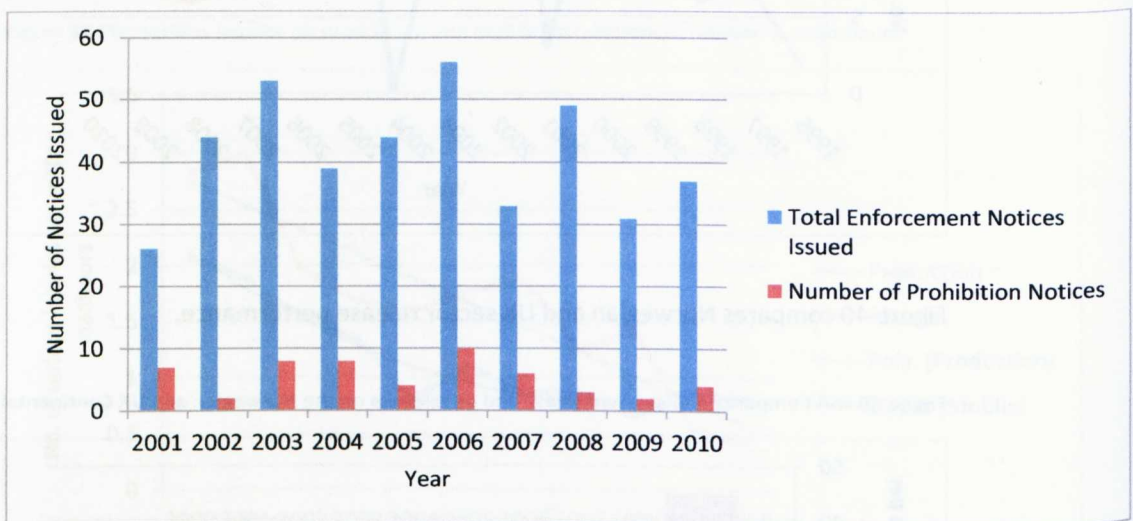
Note: Two phase refers to liquid and gas

In general, Norway has a higher number of gas releases while oil releases are similar for both Norway and the UK. However, the immediate risks and escalation potential of a gas release compared to an oil release are generally much greater.

6.5 Regulator enforcement

In the UK, a potential measure of industry safety performance is the number of regulator enforcement actions, through prohibition and improvement notices, issued to oil and gas companies operating in the UK sector (Figure 41). The data has to be treated with some caution as it does not reflect the amount of oil and gas activity in the sector over the period of the data. Again, there are no discernible trends and given the variability of previous safety performance data, it is not possible to correlate enforcement actions with safety performance.

Figure 41 UK HSE Number of Enforcement Notices Issued 2001 to 2010



6.6 Accident Causation

In the UK, post-Piper Alpha, and subsequently in the general global oil and gas industry, the introduction of an OH&S-MS was intended to prevent injury and ill health and therefore major accidents. However, there is a recognition in the OGP report [27], '*Managing major incident risks (403, April 2008)*', some 20 years after Piper Alpha and about 17 years after the introduction of HSG65, that some companies were [still] failing to effectively apply an OH&S-MS, resulting in a poor occupational OH&S performance. The OGP report also implies that because major accidents are infrequent and often there are complex failure scenarios, the OH&S-MS may not be able to identify the hazard or risks [that contribute to the major accident]. However, major accidents or

disasters, in the petrochemical industry, suggest that they are not as infrequent as implied in the OGP report. Furthermore, the trends for exploration and development blowouts also provide some evidence that since 1999 the frequency of major accidents has remained reasonably constant, i.e. there has been no significant reduction in blowout frequency. More recently, major accidents at the U.S. BP Texas refinery, and the UK Buncefield Oil Storage Depot, both in 2005, and Deepwater Horizon in 2010, reiterate the continuing susceptibility of the industry to major accidents. However, from a reporting perspective it should be noted that:

- In the 1988 OGP Safety Performance Indicators Report, no statistical account was taken of the 167 deaths associated with Piper Alpha;
- Since there were no fatalities or injuries associated with Buncefield, the event would not have had any statistical significance in the OGP Safety Performance Indicators Report;
- The U.S. BP Texas refinery major accident was not included in the OGP Safety Performance Indicators Report, 2006 [233]; and
- The IADC ASP Reports do not directly include information on blowouts, although these are one of the major accident hazards that have the potential for multiple fatalities, injuries and total loss of the asset.

It should also be noted that there is no universally-agreed definition of a 'major accident'. For example, in Article 3 of the EU Control of Major Accidents Hazards Directive (Seveso II), three criteria must be fulfilled:-

- the accident must be initiated by an 'uncontrolled development';
- one or more 'dangerous substances' listed in Annex I of the Directive must be involved;
- and
- the accident must lead to 'serious danger' to human health, the environment or property.

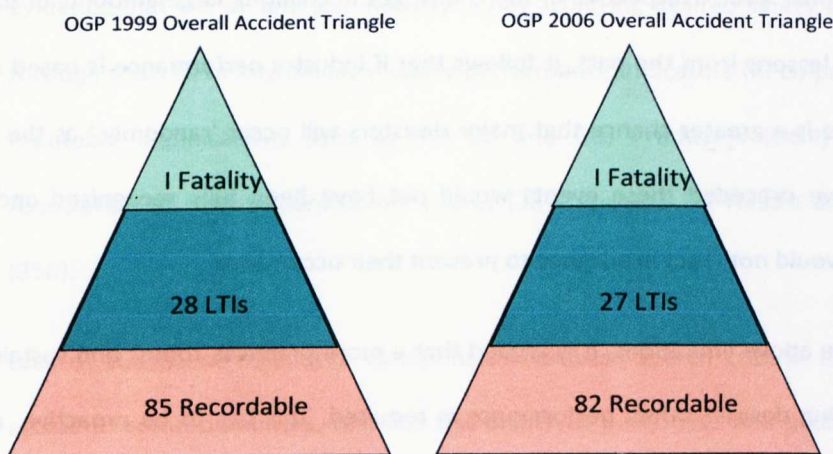
However, in the UK Statutory Instrument 2005 No. 3117, The Offshore Installations (Safety Case) Regulations 2005, 'major accident' means:

- *"a fire, explosion or the release of a dangerous substance involving death or serious personal injury to persons on the installation or engaged in an activity on or in connection with it;*
- *an event involving major damage to the structure of the installation or plant affixed thereto, or any loss in the stability of the installation;*
- *the collision of a helicopter with the installation;*
- *the failure of life support systems for diving operations in connection with the installation, the detachment of a diving bell used for such operations, or the trapping of a diver in a diving bell or other subsea chamber used for such operations; or*
- *any other event arising from a work activity involving death or serious personal injury to five or more persons on the installation, or engaged in an activity in connection with it".*

The HSE hydrocarbon release data and SINTEF Blowout data provide more reliable sources of information since, in the main, their reporting is based on statutory requirements, e.g. UK RIDDOR, whereas OGP and IADC are entirely voluntary and this should be taken into account in the analysis. While injury-based trends generally suggest a continuously improving performance, the non-injury, i.e. hydrocarbon release based trends (SINTEF blowouts and UK HSE hydrocarbon releases) imply, at best, a relatively level or deteriorating performance. As previously discussed, the hydrocarbon risk tends to dominate the overall risk profile and the offshore industry and HSE need to monitor offshore hydrocarbon releases, since these are widely-seen as the offshore equivalent of the '*Signals Passed at Danger (SPADs)*' hazard on railways [356]. The large variation in annual safety performance data, lack of discernible trends, and in some cases missing data, provides a fragmented picture of overall safety performance. For example, in terms of accident

theory, failure to report instances of property damage and near-misses constitutes a significant omission as it effectively eliminates the opportunity to address their causes before the failures that contributed to these events collude with other factors, resulting in a more serious outcome. Also, applying the Bird accident ratios (1:10:30:600) to the OGP Safety Performance Indicators – 2006 data [233], comprising 115 fatalities, theoretically there would have been 1150 minor injuries, 3450 cases of Property Damage, and 69000 near-misses. Consequently, the absence of over 70,000 events from the data is obviously a serious loss of valuable information. The published OGP Safety Performance Indicators for the years 1999 and 2006 are shown in Figure 42.

Figure 42 OGP Accident Triangle



Source: OGP Safety Performance Indicators 1999 and 2006

In 1999, it shows the fatality to LTI ratio of 1:28, and the LTI to Recordable ratio of approximately 1:3, with similar ratios in 2006. This is a significant departure from the ratios, and incident categories used by Bird.

It is evident that OGP, IADC and HSE, in isolation, do not provide comprehensive performance data, and when the available data are compared, they suggest potentially conflicting evidence of performance. This may be due to the voluntary requirement for reporting, the use of reactive

KPIs, and the absence of major accident data, at one end of the accident triangle, and property damage and near misses at the other end.

Furthermore, given the lack of global agreement in major accident definition and the difficulty and uncertainty when using available accident databases, this problem is likely to be amplified for global property damage and near-miss reporting. However, property damage and near-miss reporting and recording ought to be happening at the organisational level, and this information should then be fed into the process for global analysis. Since it does not appear in the global safety performance data, then perhaps it is not being [adequately] reported and recorded at the organisational level. Irrespective of the challenges in collating large amounts of data for learning adequate lessons from the past, it follows that if industry performance is based on limited data then there is a greater chance that major disasters will occur 'randomly,' as the conditions that would have preceded these events would not have been fully recognised and therefore the industry would not react in advance to prevent their occurrence

Due to the above limitations, it is argued that a more practical, robust and sustainable approach in delivering desired safety performance is required. This has to be proactive, as many of the problems associated with delivery of OH&S objectives, as discussed above, appear to stem from the limited voluntary disclosure of incident data, extensive use of reactive KPIs, and the restricted scope for a comprehensive assessment of performance that can be used to develop actions leading to sustainable improvements. Proactive hazard management also has to take place much earlier, although not exclusively, in the development process, and in particular, during the design phase. This is when many of the factors (such as error enforcing conditions) that contribute to an accident/incident can be either eliminated, or suitable and sufficient risk mitigation measures introduced which, at this stage, can be extremely cost-effective. Health and safety during this

phase, at present, tends to focus almost exclusively, on major hazards management, with only indirect effects relating to the prevention of less serious events.

6.7 Summary

During the time before Deepwater Horizon, despite relatively large historical financial losses, the industry was able to recover relatively quickly, without long term adverse impact. Therefore, the motivation and incentive to establish better long-term safety management strategies to prevent future disasters was diluted by a degree of financial resilience. However, the Deepwater Horizon major accident, and its impact on BP, may change this short-termism exhibited by the industry.

Evidence that the oil and gas industry is not achieving desired safety objectives is also manifest through analysis of key industry safety performance indicators (KPIs) provided by prominent and reputable organisations such as the Oil and Gas Producers (OGP) [210], the International Association of Drilling Contractors (IADC) [357] and the UK Health and Safety Executive (HSE) [358].

Lack of consistent definition, variations in database search criteria design, and limits on free access to some databases, restricts the ability to determine and evaluate the extent of major accidents in the industry.

It is evident that major accidents still occur, and the spread from Piper Alpha 1988, to Texas City 2005 and Deepwater Horizon 2010, is indicative of the continued recurrence of these events. These major accidents, together with many others, are generally well documented, and comprehensively investigated by independent competent bodies, with the lessons learnt being made available to the public. While the immediate causes may differ between major accidents, there are often many common root, or underlying causes, as they tend to reside within the higher levels of decision-making within large organisations. Consequently, it would appear that the lessons learnt from previous major accidents have not, historically, been adequately captured by

some organisations, and therefore the industry will continue to be vulnerable to major accidents if fundamental change (e.g. moving from safety regimes that are dominated by limited reactive approaches to one that is comprehensive and proactive) in safety management does not take place.

There are a number of organisations that publish industry safety performance data. In many instances the data is derived from voluntary submission, from member organisations, of a relatively narrow set of safety performance indicators (i.e. injurious incidents) or through legislative requirements, e.g. in the UK RIDDOR. The non-regulatory submitted and published data is focused on injurious incidents, and has omitted process safety data such as hydrocarbon releases and blowouts, or well control problems that might lead to blowouts, and these, while not always resulting in injurious outcomes, are generally the precursors to major accidents. The data also omits near-misses which, according to accident causation theory, are the precursors to more serious events. In terms of regulatory-produced data, such as hydrocarbon releases or SINTEF blowout data, it tends to be more credible and accurate but is treated independently from injurious events, although the same root, or underlying, causes of process-related incidents may also be common with injurious events.

In general all the published data is highly variable and trends are difficult to determine.

The OGP and IADC injurious data shows relatively weak trends but, in the main, suggests an improving performance. The HSE hydrocarbon release data does not show any marked improvement while the blowout data trend shows no discernible improvement. The key point is that the injurious trends generally appear to be divergent with the non-injurious data. If the industry regards the injurious data as their benchmark of safety performance, it is likely to give them a false sense of continuous improvement in safety performance, particularly as the contradictory pattern in non-injurious events is more likely to result in major accidents. This

discrepancy was emphasised in the Texas City (2005) and Deepwater Horizon investigation reports.

Similar results are found in the PSA data, although in absolute terms the number of hydrocarbon releases is generally higher in the Norwegian sector than the UK sector. The reasons for the difference have not been evaluated.

The publically-available safety performance data might give the impression that overall safety performance is improving as the KPIs are dominated by injurious events. However, this is not consistent with non-injurious safety performance data, although in both cases the annual performance data is highly-variable, making it difficult to discern any valid trending, or to extrapolate that for future performance. The current data used for benchmarking performance may be misleading and disguise an actual safety performance that has warning signals that the industry is failing to recognise, and therefore act upon.

Many separate independent studies have been carried out on accident causation. These have produced the concept of the 'accident triangle' with different studies producing variations in the ratios associated with the incident categories. However, the principles underpinning the theory are the same in all the studies. Application of the concept has not been fully implemented by the industry, and this is indicated by the absence of major accident and near-miss data published by the industry, and therefore global benchmarking against this data may lose some of its value, although it may be happening at company level. This also results in an apparent disconnect between the data published for injurious incidents and the data for non-injurious incidents, although accident causation theory suggests that there is an important relationship between these events. Failure to recognise this connection will mean that the data is partly devalued, and opportunities are lost to interrogate the data to create suitable proactive strategies for safety management.

Given the limitations of available and comprehensive data it is extremely difficult to extrapolate any firm conclusions about historical financial and safety performance and how this can be used by the industry to benchmark success or failure. It is evident from much of the data that there is considerable variation in annual performance in financial, injurious and non-injurious terms. Consequently, where the data does not exhibit a statistically significant increasing or decreasing trend it cannot be distinguished from random behaviour. Furthermore the relationship between injurious and non-injurious incidents has not been developed to present a more consolidated picture of safety performance although, according to accident causation theory, they may present similar root causes.

7. QUESTIONNAIRE

7.1 Introduction

The aim of the questionnaire used in this research was to assess whether a selected population supported the views identified in the Literature Review, case studies, and the database analysis, and to provide explanations for their views; or offer alternative views or explanations. The questionnaire is listed in Appendix C and the results and analysis are in sections 6.2 to 6.9 inclusive.

The questionnaire was organised into the following categories:

- Respondent details (Not included in this thesis);
- Occupational Health and Safety Management Systems (OH&S-MS) (Section 2.2);
- Project and Risk Management;
 - Risk Assessment (Section 2.6.2);
 - Project Management (Section 2.6.1);
- Measuring Performance (Section 2.8.1);
- Recent Safety Management Theories and Concepts;
 - Resilient Engineering (RE) (Section 2.9.4);
 - High Reliability Organisations (HROs) (Section 2.9.5);
 - Inherent Safety (Section 2.9.2);
 - Question 85 Normal Accident Theory (NAT) (Section 2.9.3); and
- General comments.

The questions were not mutually exclusive and could apply across all of the above categories plus other areas of an OH&S-MS, although they had specific relevance to the category in which they were located.

Comments were provided by some respondents for some questions, and these were copied verbatim (although some spelling and grammatical errors have been corrected for clarity), and included in the Discussion paragraphs. Abbreviations have been listed in full to aid understanding. Where respondents have named a company, it has been replaced by 'Operating Company (OpCo)' for confidentiality.

All questions, in the questionnaire, are considered equally, i.e. there is no weighting so that some questions may be more important than others; this is because, in the context of this research, it is the collective view that is of concern. This reflects the principles that underpin effective OH&S-MSs that all components need to be effectively implemented to achieve efficient and successful safety performance.

The personnel listed in Table 17 were interviewed. Six of the fifteen had not participated in the questionnaire and thus provided an independent check on the design and responses of the questionnaire. Gillham suggests that one hour of interview equates to twenty hours of analysis [359]. However, since the 15 interviewees were, based on their competencies and qualifications, able to articulate reasonably focused views, the analysis took less time than was suggested by Gillham. Names and companies have been omitted for confidentiality.

Table 17 Interviewees

No.	Name	Position	Company	Location	Type of Interview	Participant In Questionnaire	Agreement with content
1	Dr. DP	Head of Technical Safety	Oil and Gas Company	UK Aberdeen	Face to face	No	Yes
2	Mr. GR	Lead HSE Advisor	Oil and Gas Company	UK Aberdeen	Face to face	No	Yes
3	Mr. PB	Senior HSE Advisor	Oil and Gas Company	Saudi Arabia	Telephone	No	Yes
4	Mr. AL	(Senior Exploration HSSE Advisor)	Oil and Gas Company	Holland Den Haag	Telephone	No	Yes
5	Mr. DL	Senior Safety Engineer	Oil and Gas Company	UK Aberdeen	Face to face	Yes	Yes
6	Dr. DC	Senior Safety Engineer	Oil and Gas Company	UK Great Yarmouth	Face to face	Yes	Yes
7	Mr. IC	HSE Manager	Service Company	UK Aberdeen	Face to face	Yes	Yes

No.	Name	Position	Company	Location	Type of Interview	Participant In Questionnaire	Agreement with content
8	Mr. RH (Ex UK HSE Inspector)	Senior Safety Advisor	Service Company	UK Aberdeen	Face to face	No	Yes
9	Mr. PV	HSE Project Engineer	Service Company	UK Aberdeen	Face to face	Yes	Yes
10	Mr. CB	HSE Project Engineer	Service Company	UK Aberdeen	Face to face	No	Yes
11	Mrs. LH	Lead Safety Engineer	Safety Consultancy	UK Edinburgh	Telephone	Yes	Yes
Re12	Dr. MR	Technical Director	Safety Consultancy	UK Manchester	Telephone	Yes	Yes
13	Mr. JM	HSE Project Engineer	Service Company	UK London	Telephone	Yes	Yes
14	Mr. RF	Lead Safety Engineer	Safety Consultancy	UK Warrington	Telephone	Yes	Yes
15	Mr. SvdL	Director	Safety Consultancy	UK Aberdeen	Telephone	Yes	Yes

Notes: HSE is Health, Safety and Environment. HSSE is Health, Safety, Security and Environment

Given that the vast majority of discussion coincided with the findings from the Literature Review, the deductive analyses, and results from the questionnaire, there was little merit in conducting more interviews, especially as the six who had not participated in the questionnaire offered no significant added-value to the research.

The results have been categorised for ease and consistency. It should be noted that some comments cross various categories but are assessed for their primary relevance to a particular category. Each bullet point represents a statement made by one of the interviewees. Each of the following categories may contain statements made by one or more interviewees.

7.2 OH&S-MSs

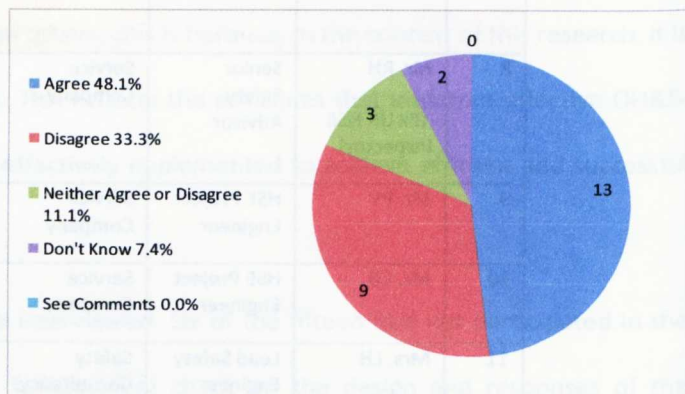
The organisation manages safety with the same degree of expertise and to the same standards as other core business activities

Comments provided by respondents

None

Discussion

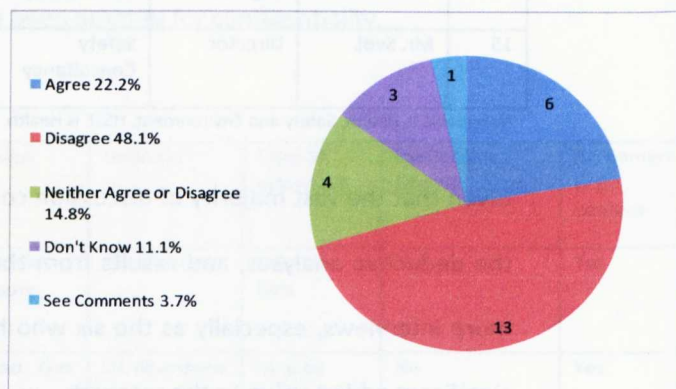
In principle the majority of oil and gas companies state that safety is equally as important as other elements of the business.



The current safety management system model lacks definition of its application during all the lifecycle phases of a development

Comments provided by respondents

None

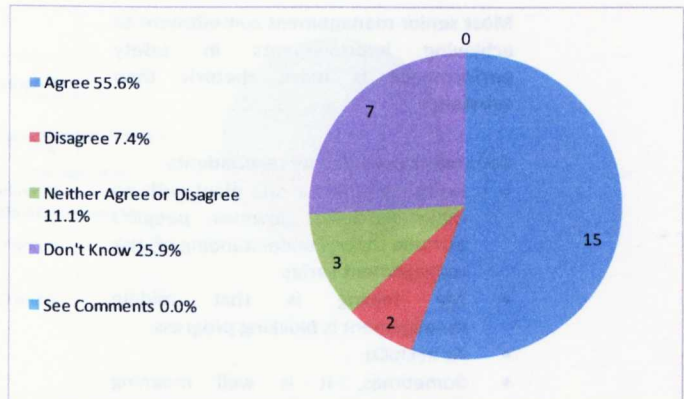


Discussion

OH&S-MSs assume that the principles that underpin particular models can be applied throughout the lifecycle phases of a development. However, there are some differentiating features within lifecycle phases that require some explanation of how the model, or its elements, could be successfully and effectively applied. For example, this may relate to emphasis where, during the design phases, inherent safety and process safety KPIs are much more critical than occupational safety. However, most disagree that the models lack this emphasis.

The total money and resources in general, allocated to various parts of the business is largely influenced by company culture.

Comments provided by respondents
None

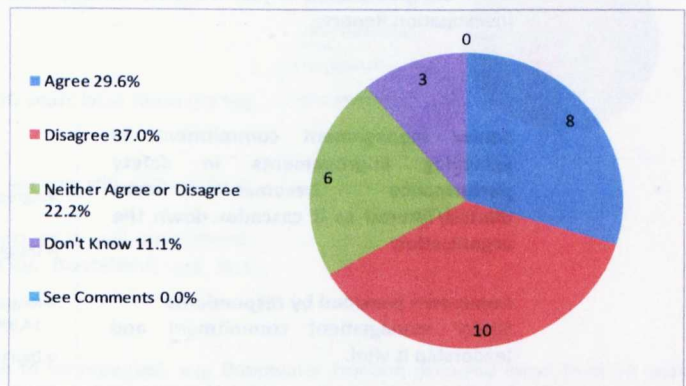


Discussion

Culture is considered to be the driver that enables the organisation to achieve its objectives. Since there are competing demands for finite resources, decisions have to be made about the allocation of these resources. A company with a strong safety culture is more likely to allocate a greater share of its overall resource allocation towards safety performance than a company that may be indifferent to safety, or where profit is paramount, at any cost. The majority agree that culture is the primary driver.

The safety culture in the organisation always means that safety gets the resources it needs to achieve safety performance targets

Comments provided by respondents
If safety culture can be 'good' or 'poor'.



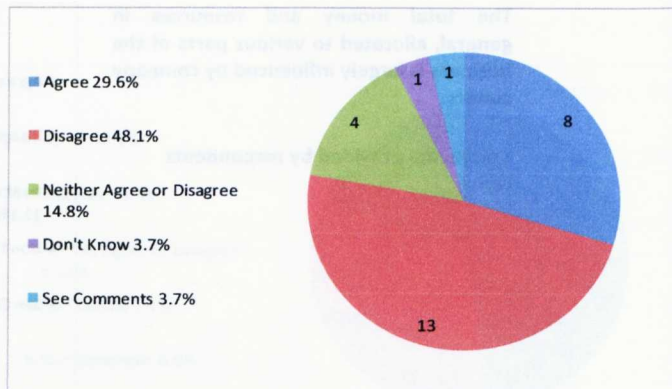
Discussion

A company may have a very positive safety culture but that does not necessarily mean its allocation of resources to achieve continued and sustainable improvement in safety performance is a given. External influences, such as stakeholder values, may well divert resources from safety in order to improve profit margins, especially if safety performance is seen to be adequate when compared to that of competitors. The majority disagree that the organisation always gets the resources it needs to achieve safety targets.

Most senior management commitment to achieving improvements in safety performance is more rhetoric than substance

Comments provided by respondents

- Everyone wants a safe plant with no major incidents. However, people's attitude to, and understanding of, risk management varies
- My feeling is that middle management is blocking progress.
- As in OpCo.
- Sometimes, it is well meaning rhetoric!



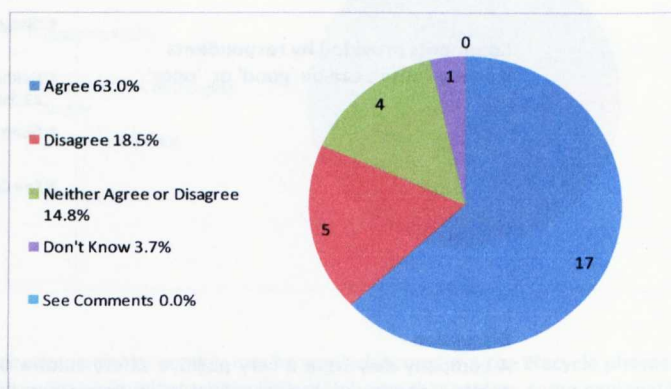
Discussion

In developed nations; the ethical and legal imperative requires that people are protected against harm. Consequently, companies normally set an annual safety performance target that seeks improvement on the previous year's performance. The ability to achieve this performance is based on factors such as company culture and resource allocation. However, what companies do and what they achieve may differ considerably, and without any reconciliation of performance or incentive to meet targets, objectives may not be met. If there is no significant recourse when targets are not met, then the process is largely devalued and is unlikely to produce continuous and sustainable improvements. Most disagree that it is just rhetoric, although this is contradicted by the BP Texas City and Deepwater Horizon Investigation Reports.

Senior management commitment to achieving improvements in safety performance becomes more diluted/filtered as it cascades down the organisation

Comments provided by respondents

Senior management commitment and leadership is vital.



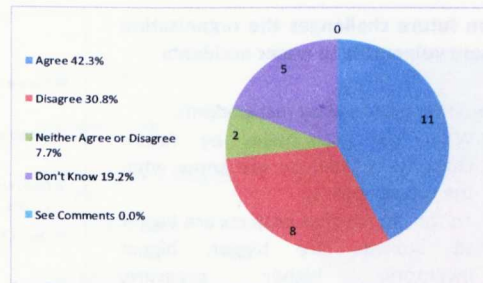
Discussion

In large organisations, even if there is a genuine management commitment to make safety improvements this intent can be diluted as it cascades through the organisation, particularly if elements of middle management cannot buy into the commitment, have insufficient resources to achieve the necessary results, or do not believe there is a genuine senior level commitment. The majority agree that this is the case.

There is effective workforce involvement in producing safety improvements, e.g. through safety committees

Comments provided by respondents

- We do expect more from the contractor world.
- In a major hazards plant (with safety cases) this is generally true, but usually because the legislation requires it.
- Generally for occupational safety; less so for major hazard safety.



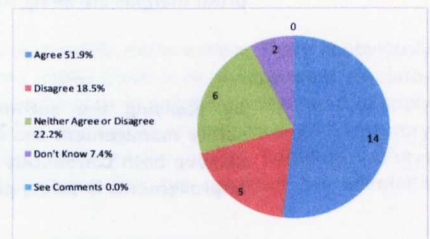
Discussion

The people who really know what is happening in an organisation are those who are typically at the workforce. Consequently, in the UK, it is necessary to involve the workforce in policy and decision making. The majority agree that the workforce is adequately involved in this process.

The lessons that should have been learnt from major accidents such as Piper Alpha have been adequately captured and addressed by the organisation

Comments provided by respondents

- But have to be repeated.
- Just after Piper Alpha this happens, but 20 years later there is a big shortfall.
- Generally true.
- On the whole yes, but realisation that we are still vulnerable is weak.
- Piper Alpha has been around for 23 years so is well understood. More recent major incidents (Texas City, Buncefield) are less understood.



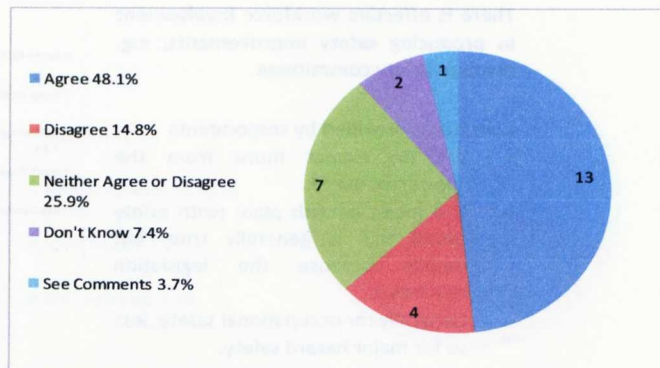
Discussion

Incidents, including major accidents, continue to be repeated, e.g. Deepwater Horizon occurred more than 30 years after Piper Alpha. Most agree that the lessons learnt from Piper Alpha have been adequately captured to prevent a similar event but this might relate to the specific causes that led to this particular disaster. Consequently, some comments imply that the lessons from Piper Alpha have been addressed but that other contributory factors have caused subsequent disasters. This may be the case where the apparent causes are likely to vary between disasters but there may be relatively common root, or underlying, causes.

Given future challenges the organisation is more vulnerable to major accidents

Comments provided by respondents

- What do you mean by future challenges? How do we know what the future holds?
- To the degree that projects are bigger so hazards are bigger, bigger inventory, higher pressure, temperature, more complex operations. I take vulnerable to mean 'more exposure'.
- Physically, they are no more vulnerable. Politically, they will be more vulnerable.



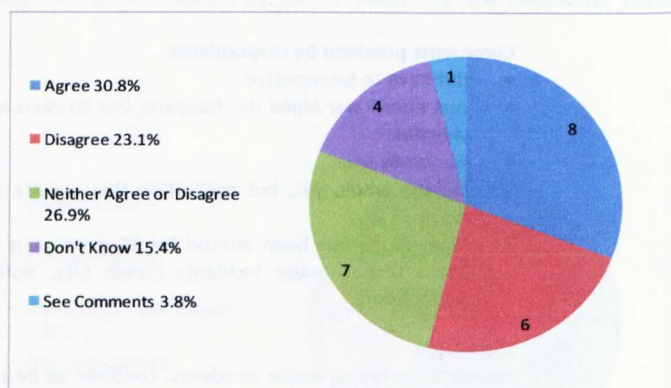
Discussion

The oil and gas industry is facing greater competition from renewables, and is operating in more technically, politically and geographically complex areas for exploration and exploitation. Consequently, development costs are rising while profit margins are being squeezed. This adds to the pressure to compromise safety. The majority agree this is the case

By applying the current approach to safety management the organisation can achieve both continuous and sustainable improvements in safety performance

Comments provided by respondents

- Agree, but can be done better!
- Yes but the problem is the new OpCo HSE-Control Framework hasn't been properly rolled out and people are unaware of the local documentation needed to implement it.
- There is no consistent approach. The current approach is all over the map. If/when the new HSSE&SP Control Framework is fully functional THEN the organisation will be well placed for continuous improvement.
- It can. The challenge is will the organisation implement the systems to deliver this.



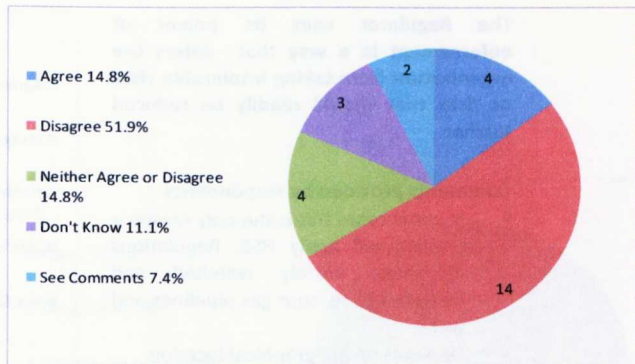
Discussion

Currently OH&S-MSs have been in place for at least a couple of decades. However, policies, practices and techniques have had to be changed to reflect the dynamic nature of global oil and gas operations. This is one of the reasons the UK moved away from prescriptive to goal-setting regulatory regimes. The majority agree that the current OH&S-MS is adequate to meet future challenges, the caveat being the ability to apply these systems consistently and effectively.

The Regulator has sufficient resources to carry out inspections that are frequent enough and in appropriate depth to discharge their duties

Comments provided by respondents

- Yes in the UK. The situation is different in other countries.
- Regulators are looking for gross incompetence, not at good performing majors that are ahead of the pack.
- Only one (part-time) regulator for the whole New Zealand industry.
- Depends on geographical location. See Macondo report for view on U.S.
- Depends on the country. I would agree in the UK, but not in the U.S. Third world countries have no effective regulator.



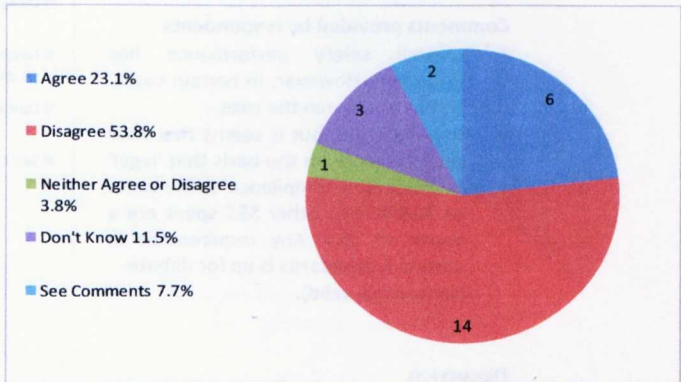
Discussion

In a goal-setting regime, organisations have significant freedom to determine safety performance. There is obviously the potential to abuse this freedom (as illustrated in Deepwater Horizon) unless there is an independent regulator monitoring and intervening, etc. It also emphasises the need for companies operating in a global environment to apply good/best practices, based on their global experience since the level of regulatory competence and statutory requirement may vary considerably between countries. If companies work to the lowest common (safety) denominator, this will be reflected in their performance. The majority disagree that the regulator has adequate resources to discharge this duty.

The Regulator provides authoritative, proactive and accessible advice and is readily available to all personnel

Comments provided by respondents

- Yes in the UK. The situation is different in other countries.
- Advice on simple matters.
- Where he can - resource constrained.
- Depends on geographical location.
- In the UK, advice tends to be accessed by the safety group. Distribution to all personnel is variable.



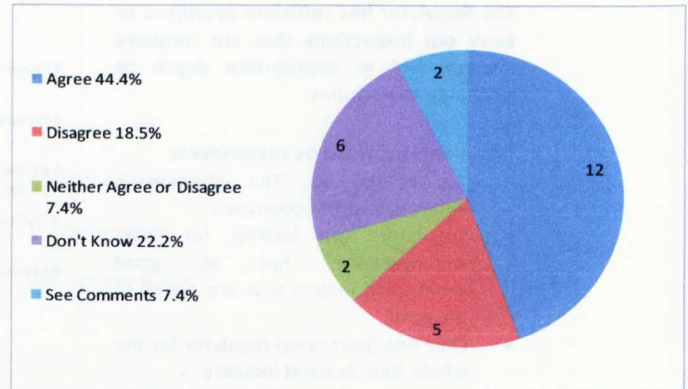
Discussion

Often companies will take advice from the regulator given their status. Consequently, there is a move to make the regulator more proactive, rather than reactive. Given their wider remit, they see a much broader group of companies within their industry sector, and can benchmark to provide examples of good and best practice. The majority disagree that the regulator has this approach, and where it exists it may be variable.

The Regulator uses its power of enforcement in a way that deters the organisation from taking intolerable risks or risks that should readily be reduced further

Comments provided by respondents

- In some cases this is the only reason a project will apply HSE. Regulations are very closely watched and complied to re. sour gas pipelines and wells.
- Depends on geographical location.
- In the UK.



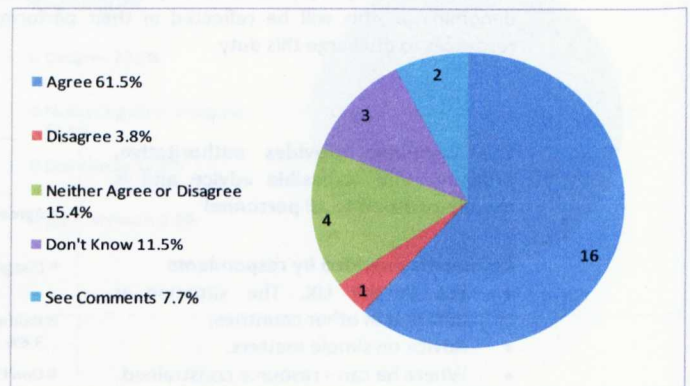
Discussion

The calculation and determination of risk may be extremely variable. In a goal-setting legislative regime, it is not for the regulator to define these criteria, other than through guidance or the demonstration of ALARP in offshore safety cases or onshore safety reports. Proactive regulator intervention is more difficult given that there is a much broader approach to risk tolerability by different companies, with different risks. Consequently, the regulator might become more reactive, given their resource limitations, only intervening when there are serious incidents, e.g. fatalities. The majority agree that the regulator does use its power of enforcement to help improve safety performance, other than in high profile failures which seems contradictory.

Since Piper Alpha, the goal-setting regulatory regime has improved safety performance more than if it had remained a prescriptive regime

Comments provided by respondents

- Overall safety performance has improved. However, in certain cases, this has not been the case.
- Initially it did, but it seems that now projects work on the basis that 'legal' or 'minimum compliance' is the same as ALARP, any other \$\$\$ spent are a waste of \$\$\$\$. Any requirement in company standards is up for debate (sometimes valid).



Discussion

Goal-setting was proposed and supported by the UK oil and gas industry so that it could take accountability for managing the risks it creates, and because prescriptive safety legislation was seen to lag behind the technological progress of the industry. The majority agree that safety performance has improved as a result of the goal-setting regime.

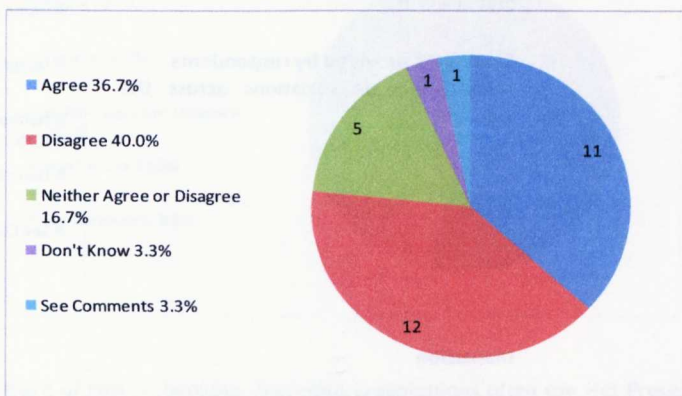
7.3 Project and Risk Management

Risk Management

Excluding the HSE Department, the concept of Risk Assessment is well understood throughout the organisation, including main and subcontractors

Comments provided by respondents

- It is well understood by more senior management. Not clear if it is understood throughout the organisation.
- Known, but not 'well understood'.
- Could be better, hence part of the improvements for 2011.



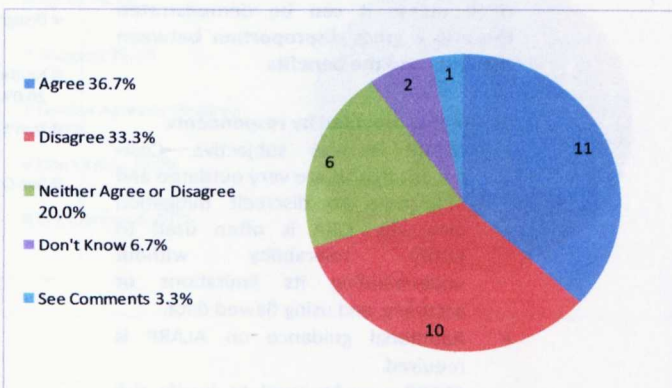
Discussion

Hazards, both major and minor, are inherent in the oil and gas industry. Therefore, total elimination of the hazard(s) is often not possible and therefore requires controls (mitigations) to reduce the remaining risks to levels that are tolerable and as low as reasonably practicable (ALARP). The concept of suitable and sufficient risk management, apart from statutory requirements, has moral and reputational benefits for organisations. The majority disagree that the concept of risk assessment is well understood in the industry, and this has significant safety performance implications, since risks that are not understood may not be adequately controlled and represent potential latent failures.

Risk assessment principles and tools are applied effectively throughout the organisations

Comments provided by respondents

- This depends on the company / project and varies widely within the industry.
- Massive misuse of the RAM (Risk Assessment Matrix).
- Risk assessment tools are widely used, but to be effective, risk management principles must be fully used (especially close out and monitoring of close out).
- The OpCo RAM is applied inconsistently across the organisation. Re-ramming is prevalent.
- Generally, where there is a strong safety group to push.



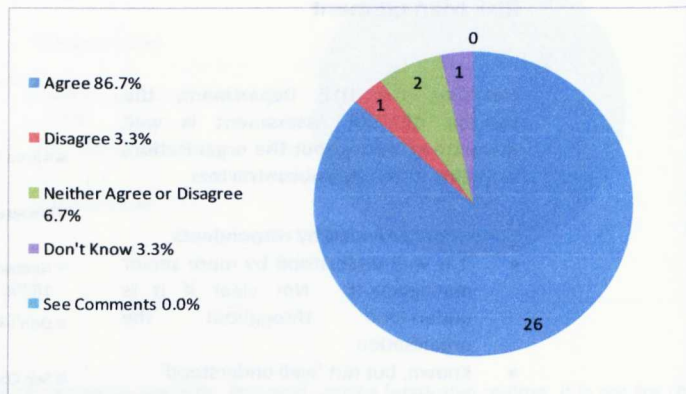
Discussion

The quantitative tools for risk assessment tend to be used by safety engineers while the qualitative tools are designed to be used by all personnel in the industry, i.e. limited specialist skills and knowledge are required. A small majority agree that the tools are applied effectively but not necessarily consistently and there can be abuse or misuse of the tools.

There are wide variations in the quality of risk assessments within the organisation

Comments provided by respondents

There are wide variations across the industry.



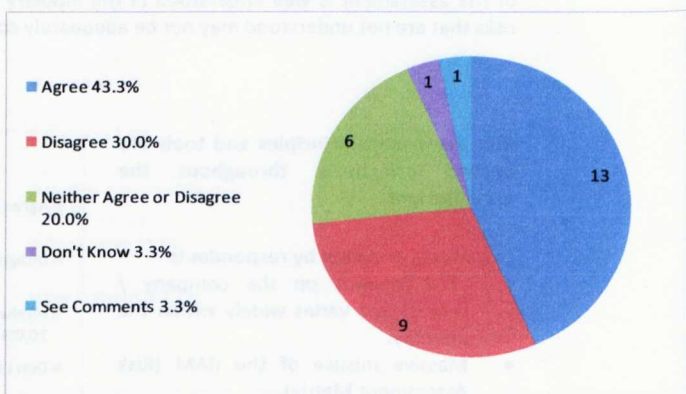
Discussion

Management of risk is, in general, only as good as the weakest link in the process. For example, successfully managing risk in one part of an offshore installation may be offset by poor risk assessment in another, particularly in tightly-coupled, dynamic processes, where failure in one area can rapidly escalate to another. A significant majority agree that the quality of risk assessment is variable.

The 'as low as is reasonably practicable' (ALARP) concept is applied on the basis that all measures/controls are initially implemented to eliminate or mitigate risks, unless it can be demonstrated there is a gross disproportion between the costs and the benefits

Comments provided by respondents

- ALARP is very subjective. Cost-benefit figures are very outdated and only used to discredit mitigation measures. QRA is often used to justify tolerability without understanding its limitations or accuracy, and using flawed data.
- Additional guidance on ALARP is required.
- ALARP may be used to justify risk improvements. However, 'reverse ALARP' (explained on the discussion from these results) to justify risk increases, is avoided.



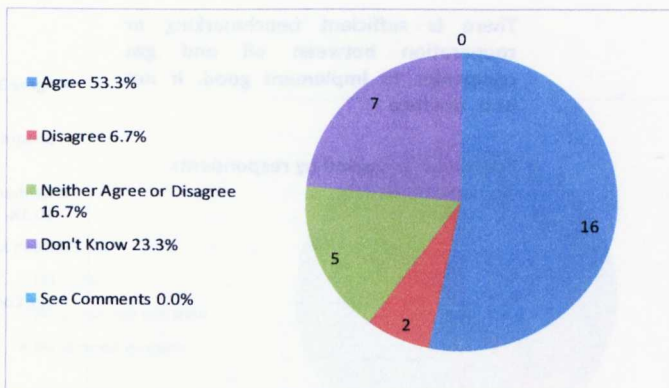
Discussion

ALARP is fundamental in the UK. ALARP has to achieve a level of risk that is tolerable but also makes economic sense. Risk mitigations should be applied until a point is reached where the cost of any further risk reduction becomes grossly disproportional to the benefits. The majority agree that ALARP is applied but given its relative subjectivity, it is open to interpretation and possible abuse.

Financial screening criteria, such as Net Present Value (NPV) do not adequately reflect risks and uncertainties because they are too prescriptive

Comments provided by respondents

- NPV is not the only criteria.
- It does not tell the whole story.



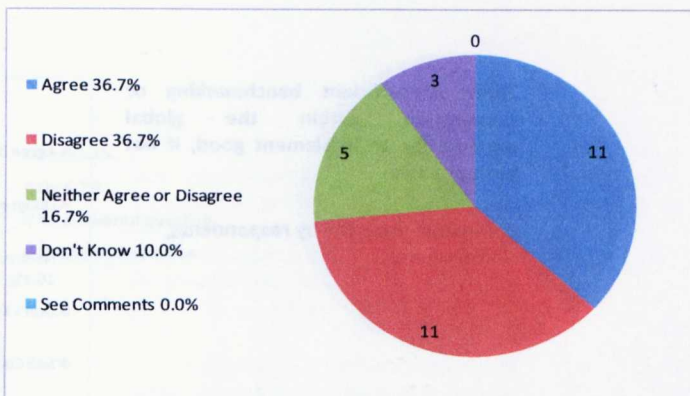
Discussion

Part of the ALARP equation allows an assessment of cost 'v' benefits. Therefore organisations often use Net Present Value (NPV) to factor costs. The majority agree that this is not a good tool since changes in legislation, interest rates, safety standards, and practices can all influence future performance.

Risks that sit in the ALARP region (e.g. quantitative 1×10^{-3} to 1×10^{-6} or yellow region of the Risk Assessment Matrix, RAM), are generally considered adequate and no further action is seriously considered to assess whether further reductions are possible at relatively low cost

Comments provided by respondents

- However, this should not be the case. All risks should be assessed to see whether risks could be reduced.
- This question illustrates the response to Q44. The example given that 'yellow' is 10^{-3} to 10^{-6} is nonsense as is the concept of the 'yellow' region being the ALARP region.
- Sometimes.

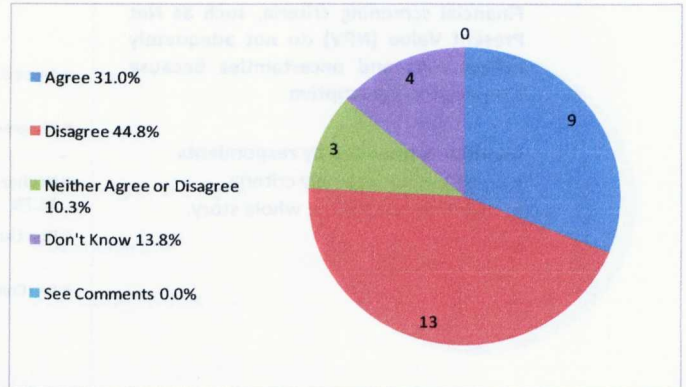


Discussion

Risks that are defined within the tolerable region of a risk profile can often be reduced but providing they sit within the tolerable range, companies often accept the risk, although it may not incur disproportionate costs to reduce the risk even further. There are obvious temptations not to do anything and therefore save money. No clear majority either way.

There is sufficient benchmarking or cooperation between oil and gas companies to implement good, if not best, practice

Comments provided by respondents
No comments.

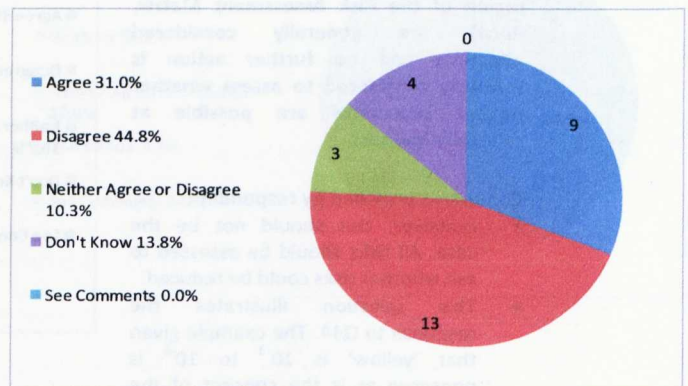


Discussion

The UKOOA (now Oil and Gas UK) decision support framework, and UK HSE guidance on risk management consider that benchmarking, and compliance, with good or best practice is one way of demonstrating compliance with regulatory provisions and standards. The majority disagree that the industry adequately benchmarks its safety practices. OGP annual safety performance reports are intended to allow the industry to benchmark performance, but given the limitations of the data this may not be effective or efficient, and can be misleading.

There is sufficient benchmarking or cooperation within the global organisation to implement good, if not best, practice

Comments provided by respondents
No comments.



Discussion

This reflects the multinational elements of most global oil and gas organisations. This question relates to internal benchmarking. The majority disagree that there is sufficient benchmarking within an organisation to identify good/best practices. The consequence is that ALARP decisions may not reflect good or best practice, although they may still be justified by organisations if the risk level sits within the ALARP region of their risk tolerability criteria.

Project Management

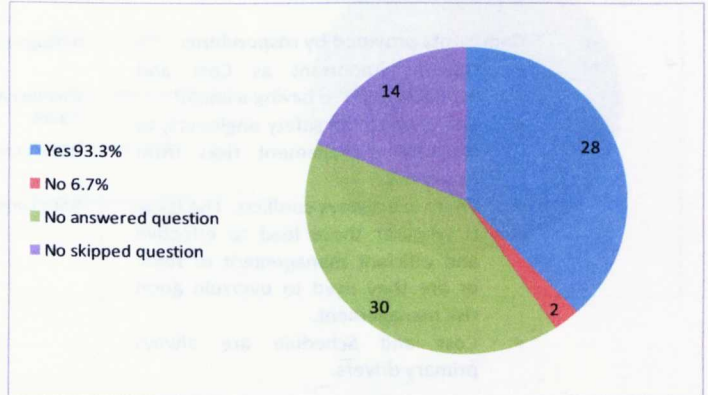
I have been involved in Projects and believe I can answer questions about some aspects of safety in project management

Comments provided by respondents

No comments.

Discussion

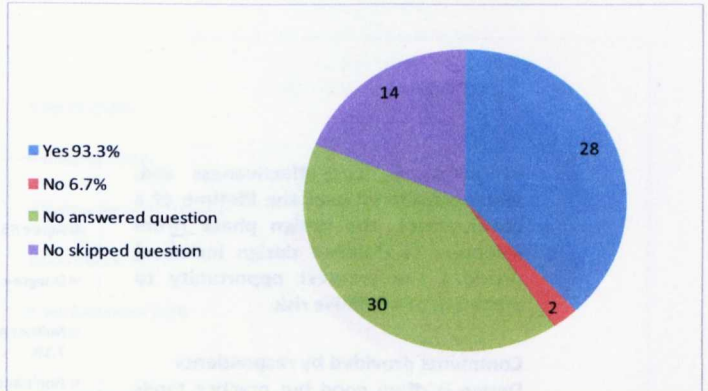
Not applicable



The requirements for managing safety risks during the design stages of a project are well understood

Comments provided by respondents

- Depends on the Project Management HSE competencies. DCAF (Discipline Controls Assurance Framework) in the OpCo helps.
- I agree. However, there is always room for continuous improvement.
- The role out of the Discipline Controls Assurance Framework (DCAF) and OpCo Standards in projects is slowly taking effect but awareness levels are low. Concerted effort is required to speed up delivery and understanding of expectations and deliverables in this area.



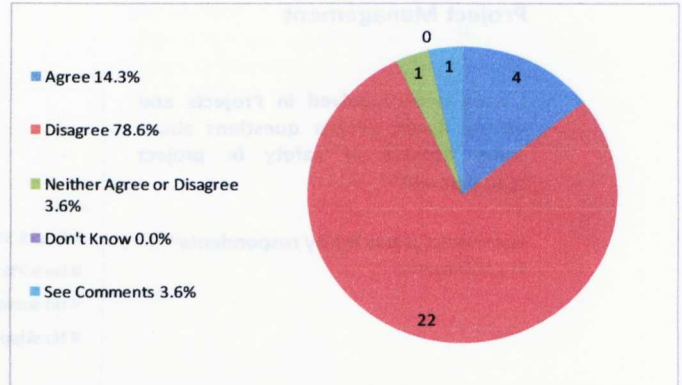
Discussion

The safety performance of a development over its lifecycle is shaped by decisions taken at the design stage. This is where decisions can be most cost-effective. However, decisions made at this stage may simply transfer costs (e.g. the costs to manage risks) to subsequent phases, as this reduces CAPEX, and improves project KPIs that include cost. The design teams are not accountable for OPEX where most of the transferred risks have to be managed. Most agree that the requirements for managing risks, in design, is understood, but this not does necessarily prevent the unnecessary transfer of risk.

There are no conflicts between the management of risks in design and other project aims and objectives

Comments provided by respondents

- HSE as important as Cost and Schedule? You're having a laugh!
- This is up to the safety engineers, to separate management risks from safety risks.
- There are always conflicts. The issue is whether these lead to effective and efficient management of risks, or are they used to overrule good risk management.
- Cost and Schedule are always primary drivers.



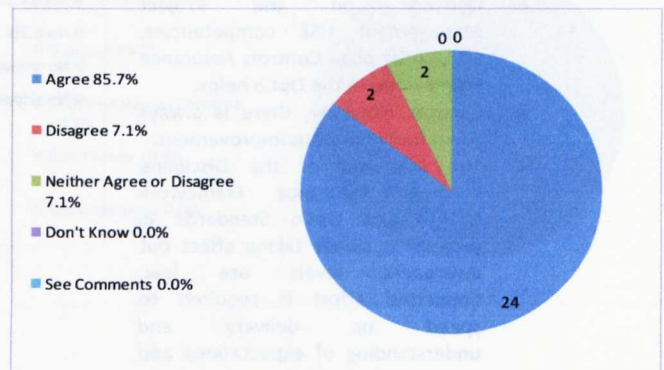
Discussion

Projects have tended to be driven, almost exclusively by cost and schedule constraints. This is not surprising given the high capital costs of most major oil and gas projects and also the frequency with which initial project costs are often significantly exceeded. This is not a new or novel phenomenon and should be part of the initial project feasibility study. Equally it is not surprising that safety could be compromised in order to preserve cost, and schedule targets, to secure project viability. A significant majority agree that there are conflicts between safety and cost and schedule.

In terms of cost-effectiveness and, when considered over the lifetime of a development, the design phase (from inception to detailed design inclusive) provides the greatest opportunity to eliminate or minimise risk

Comments provided by respondents

Design is often good but practice tends to change over the years. Review of design on a regular basis is required.



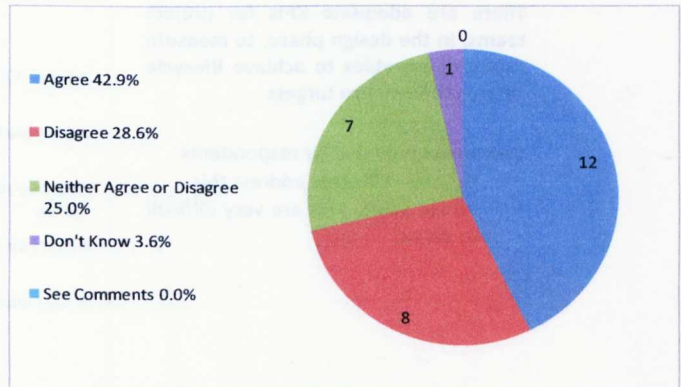
Discussion

It becomes progressively less-cost effective to make changes or modifications to facilities as the project moves through the various lifecycle phases. This is particularly so for offshore operations as this involves the logistics of transporting crews, providing accommodation (often additional accommodation vessels), and typically the need to shut down the facilities, resulting in loss of revenue. There is significant agreement that the design phase is the most cost-effective period to implement safety measures and to minimise subsequent lifecycle risks.

During the design phase sufficient resources are provided to ensure that risks are adequately identified and mitigated to demonstrate an ALARP case, not just related to design, but when considered over the entire lifetime of a development

Comments provided by respondents

- Resources are there, but processes are not understood and staff are not trained.
- An area of improvement, but further change required to deliver.
- Abandonment is often neglected.



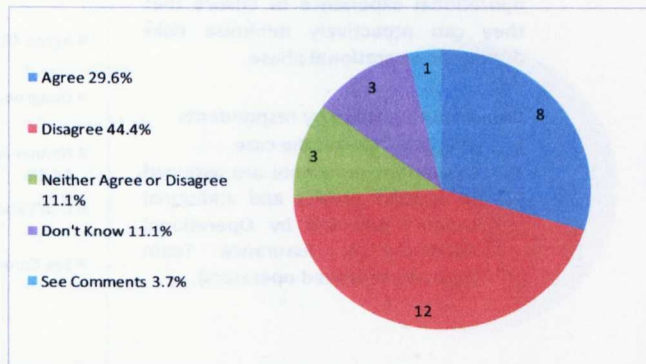
Discussion

Resources include people, and they need to have the right competencies, and experience to view risk over the lifecycle of a development. Therefore they need to be aware, not only of risk in design, but also in the subsequent phases such as operations and decommissioning (abandonment). This should ensure that risks are managed adequately over the whole lifecycle. At present ALARP is not normally applied as a lifecycle concept but is often ring-fenced, covering only certain parts of the lifecycle. Most agree that the resources are available but there may be vulnerabilities in terms of training and not taking into account the abandonment phase.

During the design phase the project team has sufficient accountability to prevent the transfer of risks to subsequent lifecycle phases

Comments provided by respondents

- Project teams simply do not deliver. Middle management does not enforce accountability.
- There can be a tendency to leave some risk management activities to the operations phase, thereby shifting costs from CAPEX (Capital Expenditure) to OPEX (Operating Expenditure). Conversely, operations often try to get the project to pay for controls they can't get through OPEX.
- Many risks are defined as requiring 'procedural control' during operation, and not considered further.



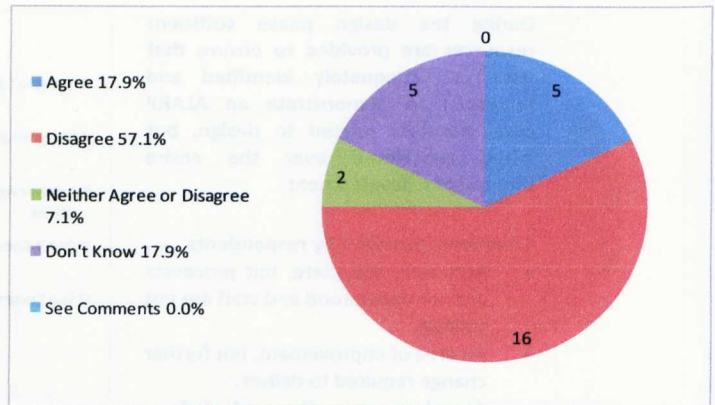
Discussion

In order to minimise capital expenditure, and often to meet project schedules, design teams sometimes transfer risks from the design phase to subsequent phases (for example, by designing a system requiring lower order procedural controls). Typically, design teams are not normally held accountable for the unnecessary transfer of risks since they are often disbanded on handover of the project. Most respondents agree they are not held accountable.

There are adequate KPIs for project teams, in the design phase, to measure safety deliverables to achieve lifecycle safety performance targets

Comments provided by respondents

- Not seen KPIs that address this.
- Design safety KPIs are very difficult to define.



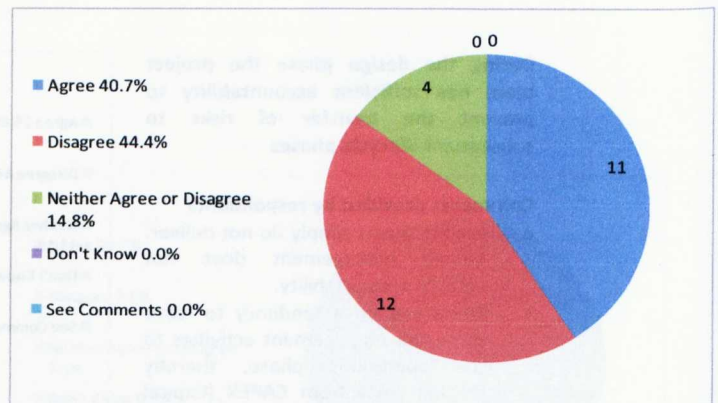
Discussion

KPIs are intended as a means to improve performance. In the design phase the KPIs are dominated by cost and schedule, and therefore there is little motivation or incentive to make improvements. For example, there is no evidence of a KPI that ensures inherent safety in design. The majority disagree that there are adequate safety-related KPIs for project teams.

Project teams in general have sufficient operational experience to ensure that they can proactively minimise risks during the operational phase

Comments provided by respondents

- This is not always the case.
- Operations personnel are assigned to support project and additional support provided by Operational Readiness & Assurance Team (typically seasoned operators).



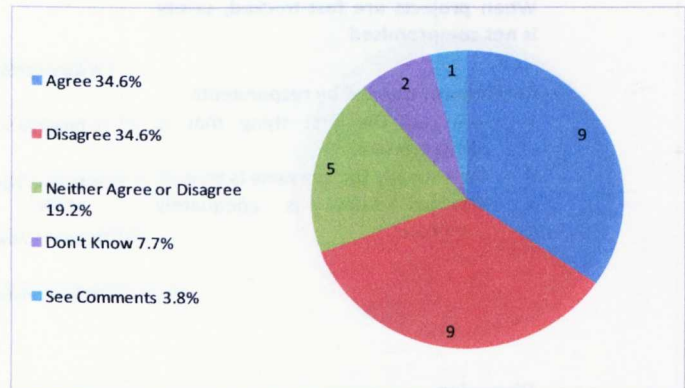
Discussion

It is normally the operational phase, within a development's lifecycle, that is the longest and presents the most significant risks to personnel. Consequently, there is value in providing adequate operational competencies, and experience, in the design phase to ensure that, for example, systems are designed to take into account operational lessons learnt, since they could be very different from those that are simply based simply on the implementation of recognised standards. Operations also have the opportunity to consider risk transfer implications, e.g. what risks they will inherit. There is disagreement that projects have sufficient operational input into the design.

The project assurance process, and its implementation, are sufficiently robust to prevent intolerable and non-ALARP risks being carried over into subsequent project phases

Comments provided by respondents

- The level of assurance undertaken is often related to the economic size of the project.
- High variability - depends on Assurance/Audit teams. Criteria for the team make-up to ensure sufficient HSE Risk Management expertise is not clear.
- Only if applied diligently.



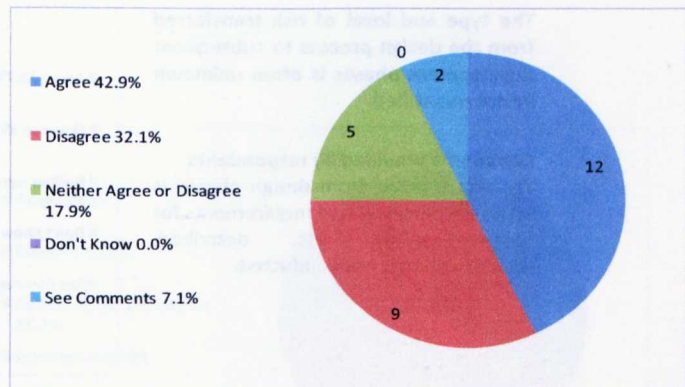
Discussion

As previously discussed, there are opportunities to transfer risks from one stage of a project to another. If an unnecessary, or high risk, is transferred to the operational phase, then the control/mitigations for this risk are likely to be less effective than, for example, in an inherently safe design. There is no clear agreement about whether the existing process prevents this type of risk transfer.

Projects targets are still driven by cost and schedule, and safety has a secondary influence

Comments provided by respondents

- Teams are rewarded on cost and schedule, workplace (construction) safety can have an effect, and design safety is hidden. Often safety is deemed to be ONLY (what I call) workplace safety with very little focus on technical/process safety. Senior management continue to use the term 'non-technical' safety! But this is complicated. Significant safety risks are usually dealt with.
- High degree of variability again – in some projects I would agree cost and schedule over-rides safety; others ensure Process Safety Management & Safety is at the forefront of design decisions.
- Strive for a good intermediate level in between.
- Safety has an equal influence, but it has to be demonstrated more rigorously than cost and schedule to be accepted.



Discussion

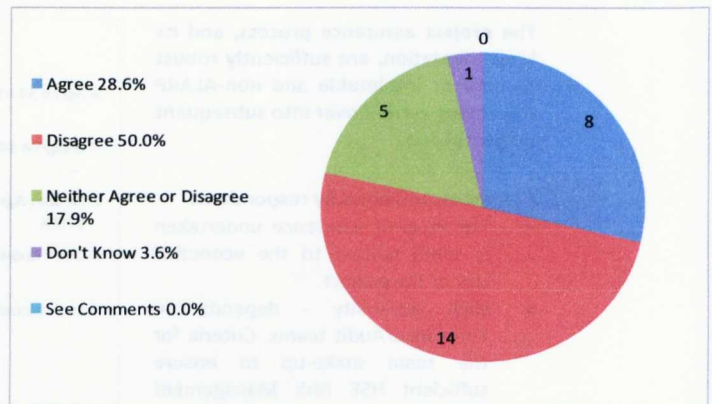
Typically project viability requires a minimum cost, short schedule, approach to get approval, particularly for marginal projects in mature operating assets. The majority agree that cost and schedule take precedence over safety, and therefore safety can be compromised.

When projects are fast-tracked, safety is not compromised

Comments provided by respondents

- Safety is the first thing that is compromised.
- Occasionally the converse is true.
- Provided safety is adequately resourced.

Discussion



Fast-tracking projects come about for a variety of reasons. One may be that as field depletion models become more sophisticated, the process facilities may need modification to maximise production. This is crucial as it relates to revenue, and the faster these facilities can come on stream, the quicker the additional revenue is generated. In these cases, the majority agree that safety is often compromised.

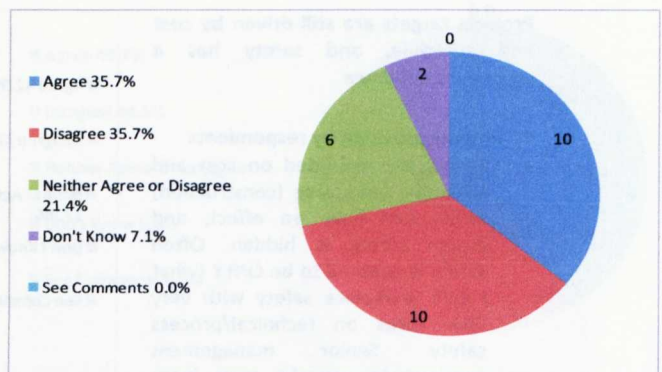
The type and level of risk transferred from the design process to subsequent development phases is often unknown or not quantified

Comments provided by respondents

The risk transfer from design phases is often documented and requirements for further study, etc. described. Quantification is not conducted.

Discussion

If risks are transferred and are not identified as part of the handover or transition from one stage to another, then they may not become evident until an incident occurs. If the risk is identified, the controls may not be able to be immediately implemented in a way that achieves ALARP. Opinion was equally divided on this question.



7.4 Measuring Performance

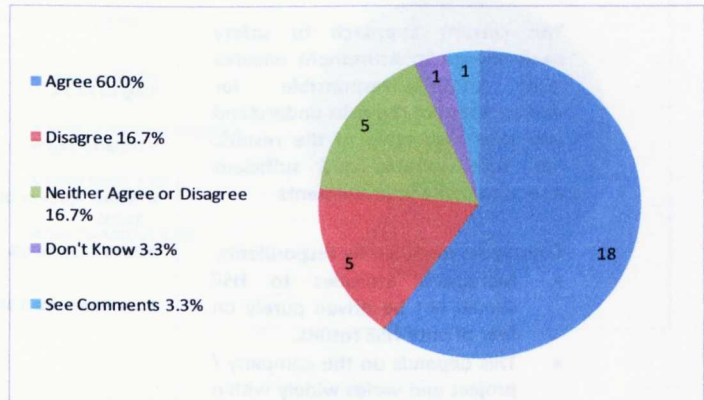
The industry is too focused on reactive (lagging/injurious based) key performance indicators (KPIs) and not enough on proactive

Comments provided by respondents

- KPIs are used more as a goal on which you should score a high, than as an indicator of possible trouble / a weak signal.
- This depends on the company / project and varies widely within the industry.
- There are plenty of examples of safety case driven performance standards and KPIs (perhaps not in U.S.).
- However, defining pro-active KPIs is not easy!

Discussion

Reactive measures (e.g. fatalities and lost time injuries), as a means of preventing accidents is too late for some people. Proactive measures try and identify what may be going wrong so that remedial action(s) can be introduced and implemented before people are injured or the environment is damaged, etc. The majority agree that the industry is too focused on reactive forms of safety performance measurement.



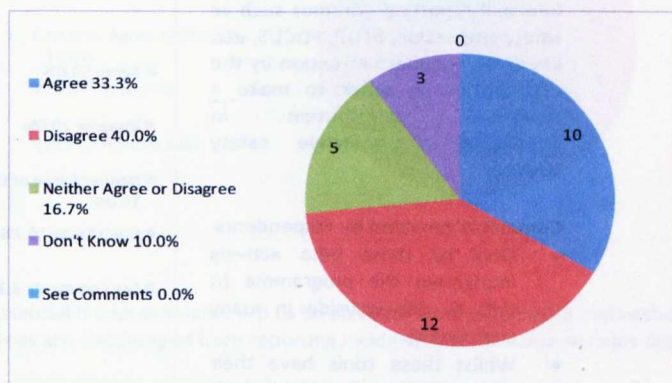
The current approach to safety performance measurement provides an immediate and reliable indication of the level of performance

Comments provided by respondents

- The preponderance of data means the big picture is lost and low-probability catastrophic consequence events are placed (consciously or subconsciously) in the "won't happen to us" bucket.
- ..for 'PAST performance. It only provides a rough indication of future performance.

Discussion

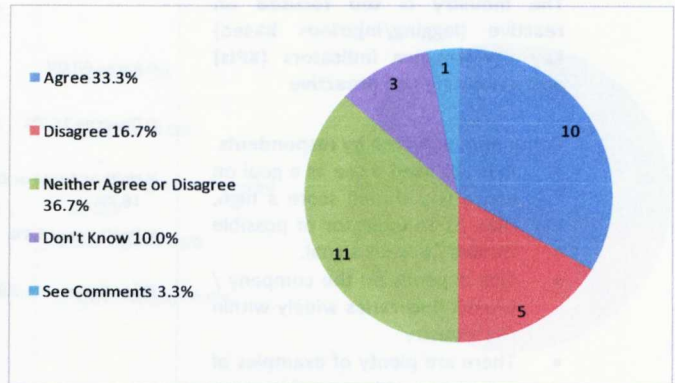
Safety metrics help an organisation define and measure progress towards organisational goals. Incomplete and/or inaccurate information can mislead organisations and result in a failure to meet safety objectives. The majority disagree that the current approach helps meet safety objectives, in some cases due to the volume of data and complacency.



The current approach to safety performance measurement ensures that those responsible for management of the risks understand and take ownership of the results, and take suitable and sufficient action to make improvements

Comments provided by respondents

- Manager's attitudes to HSE should not be driven purely on fear of poor HSE results.
- This depends on the company / project and varies widely within the industry.
- For all operators I have recently worked with.



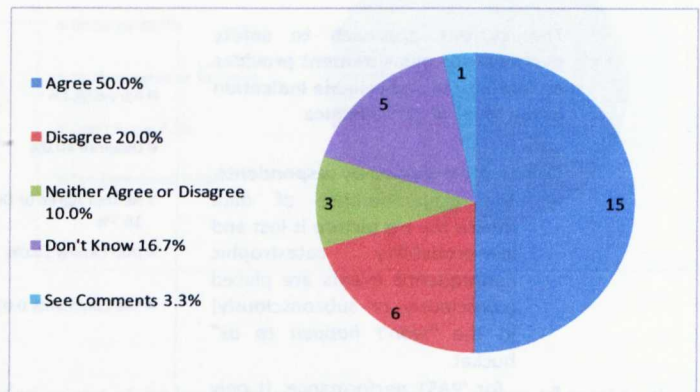
Discussion

Collecting and collating safety data is futile unless the information can be used to define strategies for improvements, and if these are effectively and efficiently implemented. Most respondents agree that there is ownership of the risks and the associated actions necessary to mitigate those risks, but if the information is poor then the benefit will also be limited.

Informal reporting schemes such as safety suggestion, STOP, FOCUS, etc. are given adequate attention by the organisation in order to make a significant contribution in developing a proactive safety strategy

Comments provided by respondents

- Only by those who actively implement the programme (it falls by the wayside in many companies).
- Whilst these tools have their place, STOP, etc. provide high volumes of data and then KPIs are used to track recording of the volume. Evaluation of data to assess trends is weak.



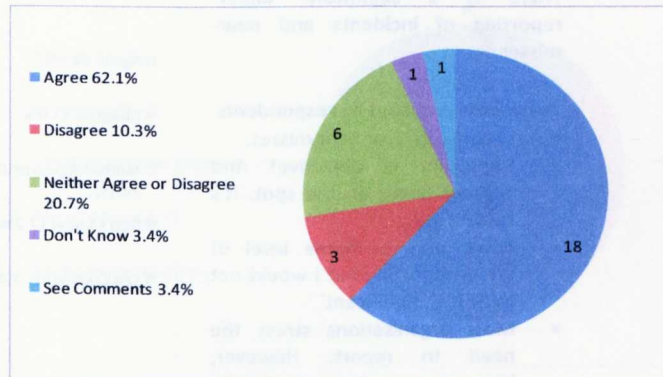
Discussion

STOP (Safety Training Observation Programme), and safety suggestion schemes are a less formal way of collecting information about safety performance. Typically, they would identify unsafe acts or unsafe conditions before they fell under the umbrella of a more formal reporting regime that incorporates near-misses, etc. The majority agree that these schemes provide valuable data but their usefulness depends on how the information is used. There is no evidence that the industry uses this type of data in an effective and efficient way to proactively promote safety improvements.

The organisation is sufficiently aware that minor hydrocarbon releases may be an underlying symptom of a larger problem that has the potential to lead to major accidents.

Comments provided by respondents

- In particular, offshore.
- Not always - some in the organisation think minor leaks are part of doing business!!!
- Not always true.
- We are not a production unit. Not relevant.

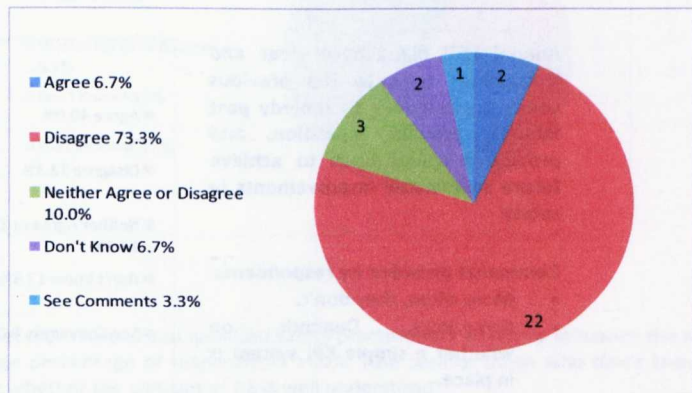


Discussion

In the oil and gas industry the major hazards are dominated by hydrocarbons under pressure. Any small release can quickly escalate into a larger release. The root causes of a small release are often similar to those for a larger release. The majority agree that organisations are aware of this relationship, although some believe that this is a normal occurrence.

Employees are discouraged from reporting incidents or near-misses for fear of reprisal

Comments provided by respondents
No comments.



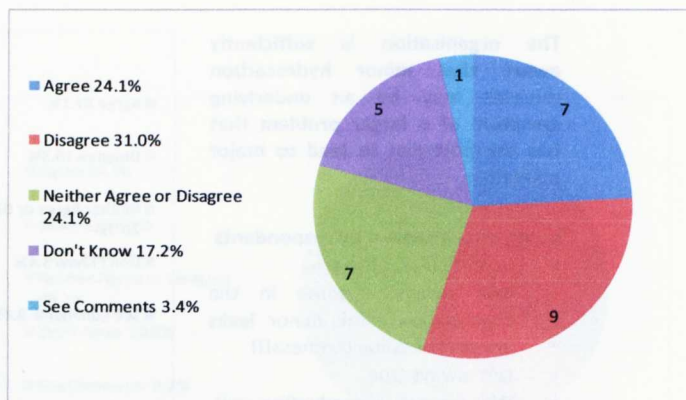
Discussion

Comprehensive and accurate data are essential if improvements are to be achieved on a sustainable and cost-effective basis. The majority disagree that employees are discouraged from reporting incidents but the value remains dependent on how this information is used.

There is a significant under-reporting of incidents and near-misses

Comments provided by respondents

- In particular, for near misses.
- Significant is objective! And without being on the spot, it's hard to say.
- There may be some level of under-reporting but I would not think it is 'significant'.
- Most organisations stress the need to report. However, human nature is to 'avoid the hassle'.



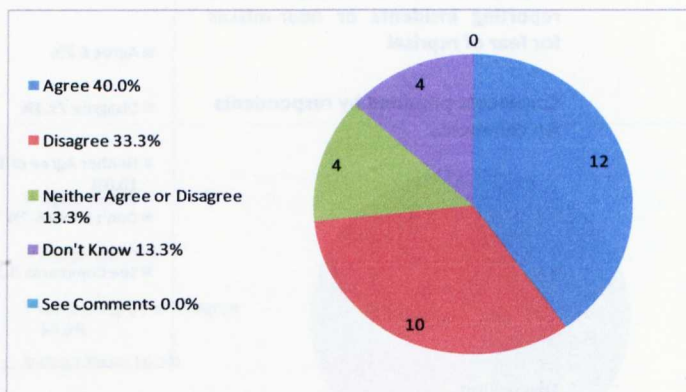
Discussion

Near-misses are a fundamental prerequisite for initiating improvements in safety as the cause(s) of a near-miss is often similar to more serious incidents. Incident causation theory advocates that by identifying, and then minimising, near-misses by addressing their root cause, it should then be possible to prevent more serious incidents. The majority disagree that there is under-reporting of incidents, but also indicate that the value depends on how this information is used.

Annual HSE plans have clear and transparent links to the previous year's performance to remedy past failures, prevent repetition, and provide a sound basis to achieve future sustainable improvements in safety

Comments provided by respondents

- More often, they don't.
- Sometimes. Depends on whether a simple KPI system is in place.



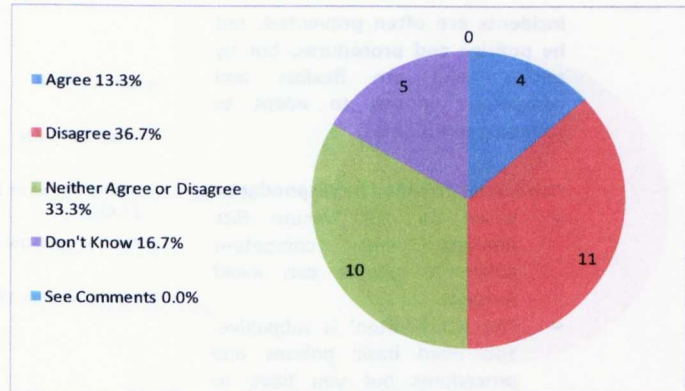
Discussion

To achieve continuous and sustainable improvements in safety it is necessary to set plans for how this can be achieved. Normally this is by analysis of previous performance to establish what went right and what went wrong, so that actions can be taken to build upon the good practices and rectify the bad. The majority agree that HSE plans, in principle, fulfill these requirements.

The resources provided to effectively implement the annual HSE safety plan are always adequate to achieve success

Comments provided by respondents

- Line commitment can improve.
- This depends on the company / project and varies widely within the industry.



Discussion

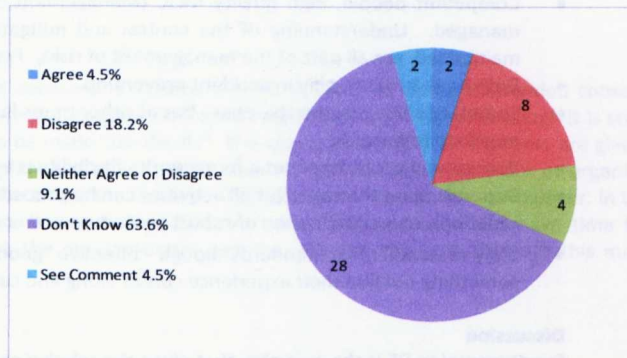
For any plan to succeed it requires the resources to meet its aims and objectives. More people than not disagree that HSE plans are given sufficient resources to meet objectives.

7.5 Resilient Engineering

The concept of Resilient Engineering (RE) is well understood.

Comments provided by respondents

None



Discussion

This question was predominantly aimed at experienced and qualified safety practitioners who help influence the means of improving safety performance. A large percentage of respondents >80%, (the sum of those who don't know and those who disagree) are uncertain about whether the concept of RE is well understood.

Incidents are often prevented, not by policies and procedures, but by people who are flexible and competent enough to adapt to changing conditions

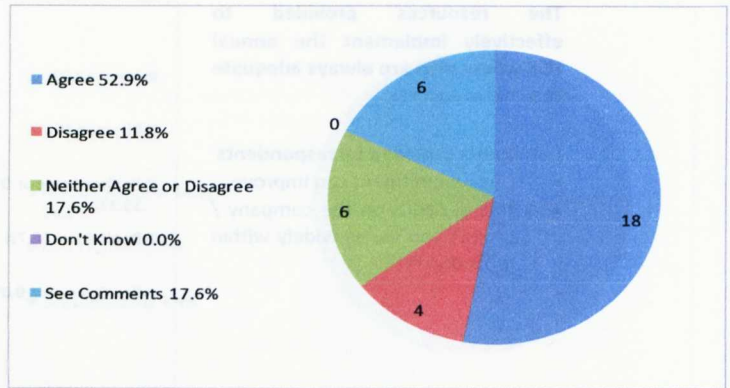
Comments provided by respondents

- Based on Last Minute Risk Analysis and competent judgment, people can avoid incidents.
- The word 'often' is subjective. You need basic policies and procedures but you have to back this up with training and competence assurance plus common sense.

- Policies and procedures cannot account for all possible incidents and should always be implemented in conjunction with training and competence management.
- Policies and procedures are necessary. However, competent people to apply these procedures are also necessary.
- But policies and procedures are part of the equation.
- Competent people, high quality MOC (Management of Change) etc. are all important to ensure hazards are managed. Understanding of the control and mitigation measures, what they are, and how performance is maintained, are all part of the management of risks. People have a key role, but are not the only control.
- Both have a role to play in accident prevention.
- Sometimes this may be the case - but at other times last minute changes without proper thought or assessment may lead to hazards.
- Policies and procedures set a framework - flexibility is essential to adapt to specifics.
- Depends upon the task. Not all activities can be proceduralised into black and white (such as effective manner of isolation), so a combination of robust procedure and competent personnel is required.
- They must still meet standards though - effective "good old boys" may be non-compliant and still successful until something outside their experience comes along and catches them.

Discussion

Fundamental to RE is the assertion that given the relative complexity and dynamic nature of organisations and systems, accidents are often prevented by people rather than by hardware or software controls. There is general agreement that this is the case but it is subject to people having the necessary competencies in combination with other control mechanisms. However, there is also recognition that people may be increasingly vulnerable to error when exposed to factors such as time pressure or operating outside their 'comfort' zones.



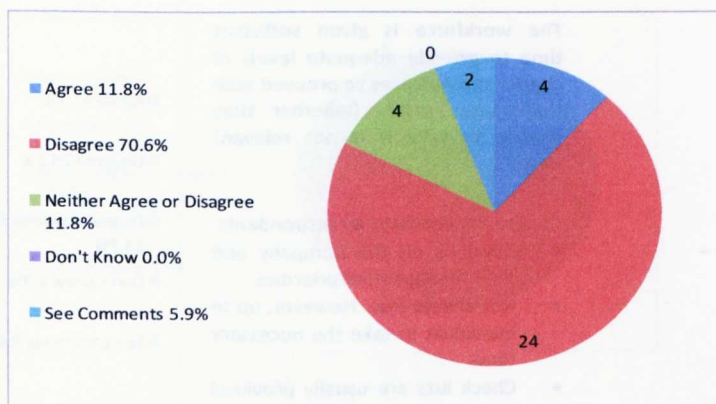
Personnel are always given sufficient time to reflect on decisions to ensure avoidance of any unintended consequences

Comments provided by respondents

- Sometimes it's external pressure but in many cases also hasty work.
- A lot of middle management pay lip service to HSE but do not make themselves fully aware or take ownership and implement HSE MS. They may say they do but cost and schedule always come first.
- Sometimes. The nature of the business requires decisions to be made on the fly.
- Not always true, however. Up to the individual to take the necessary time.
- But people do not always choose to take sufficient time.
- In theory, all O&G operators stress the importance of this. However, not all personnel take this time or know what to consider.

Discussion

The ability for people to take informed decisions is necessary in RE in order to avoid unintended consequences. A large percentage disagree that people are always given sufficient time to make decisions, although it is stated by one respondent that decisions often have to be made "on-the-fly". It is also stated that even if people are given the time, they may not choose to take it. Given plant complexity, tight-coupling and the dynamic nature of organisations and processes, this supports the need for inherent safety to avoid the potential for human error. However, in the absence of inherent safety, the importance of ensuring that people are adequately prepared and have time for suitable decision-making, becomes more critical, the more complex and dynamic the changes, although this may not be a solution in the event of emergencies.



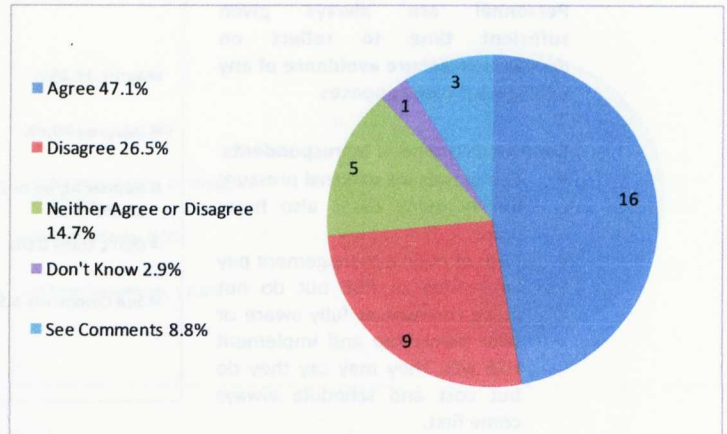
The workforce is given sufficient time to provide adequate levels of checks and balances to proceed with their tasks safely (whether they choose to take it is not relevant here)

Comments provided by respondents

- Depends on the Company and their management priorities.
- Not always true. However, up to individual to take the necessary time.
- Check lists are usually provided but people get used to the list and often neglect to actually check the status as per the tick boxes
- Extremely company specific.
- Within the OpCo, various procedures and work instructions have been implemented with a view to identifying and analysing the work at the location in question, and taking measures to minimise such risks and demonstrate that control measures have been defined. This has to do with procedures and work instructions relating to Work Planning, Project Risk Analyses, Safeguarding of Installations and Work Safety Plans. The Project Risk Analysis (PRA), in particular, has the aim of effectively identifying and communicating the risks of work activities in relation to the production system, and the interactions between the various work activities on site. The outcome of a PRA is intended to establish those measures that will create a safe workplace on the basis of the planned activities.
- Pressure to get production back on track, either directly or indirectly, influences the level of checks and balances performed.
- Pressure at a site to get the job done may mean that adequate checks are not carried out in accordance with procedures.
- Team input to e.g. toolbox talks, is far better than a single person who just wants to get on with a job.

Discussion

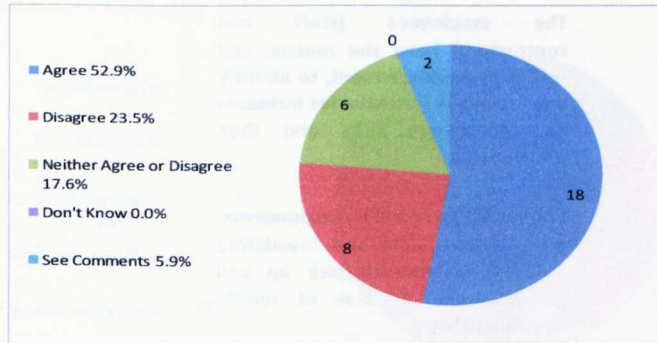
RE suggests that levels of success cannot be maintained when, for example, there is too little time for appropriate checks and balances. The majority agree that people are given time to allow them to carry out their tasks safely, although a significant percentage still disagrees. Comments show that the processes and procedures, including planning and toolbox talks, support the provision of checks and balances, but time constraints might dilute their effectiveness. It is also dependent on people having the discipline to use the tools that are available (e.g. checklists, to ensure adequate checks and balances).



The company emphasis on factors such as cost, schedule, production etc. has had, and continues to have, a detrimental impact on safety

Comments provided by respondents

- Reference big incidents all over the world.
- In general within the industry an emphasis on cost, schedule etc. would have had an impact on safety but this has been partially outweighed by the improved training which is given to personnel.
- The culture from a company level has been changing over the last 5 to 10 years, with respect to safety and its various external factors such as cost schedule and production. Whether this has been fully accepted by the grassroots management and personnel is still variable. If there is no clear distinction, then they will have an impact.
- In many cases cost and schedule still threaten safety performance in both project execution and in operability issues, including Human Factors Engineering (the discipline of applying what is known about human capabilities and limitations to the design of products, processes, systems, and work environments) issues, particularly.
- Whatever is preached, these factors will always be a consideration.
- This may not be directly related. However, there are signs of this.



Discussion

RE argues that a company is safe if it is impervious to perturbations and that systems need to be resilient against various threats [affecting safety performance]. Cost, schedule and production pressures can create the conditions that can contribute to unsafe acts and conditions, and deviations from policies and procedures, etc. The majority of respondents agree that these factors still exist but there are potential mitigations such as training and changes in [safety] culture. Cost and schedule were dominant factors that contributed to the Deepwater Horizon blowout.

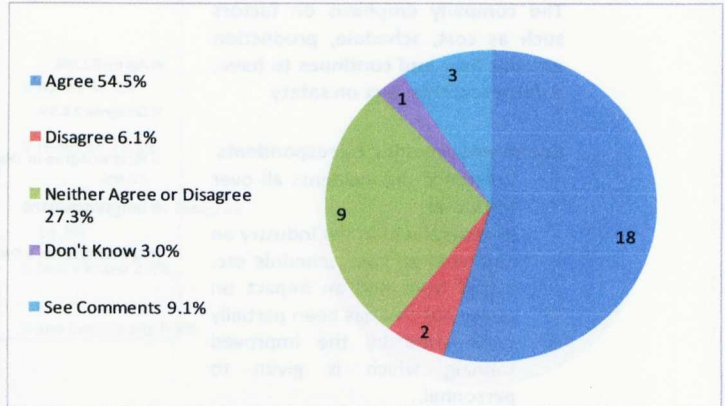
The employees (staff and contractors) have the means, and sufficient empowerment, to identify any increased potential for incidents or unnecessary risks and then prevent them

Comments provided by respondents

- It's their right and mandatory task to mention/pick up and intervene in case of unsafe situations.
- The employees should have the means. Whether they have the empowerment will vary from location to location.
- I've worked on as many projects that do, as projects that don't.
- The changing demographic across the industry means that overall experience is less, and thus empowered or otherwise, individuals do not have the confidence to always speak up.
- Sometimes! But a lot of contractors are probably concerned that refusing to do a task will lead to no repeat work for the company...
- In general all O&G operator personnel have this power, although not always the knowledge to exert it.
- They can frequently identify them. Prevention: the jury is still out.
- Identification of hazards and risk assessment is generally the easy part but follow-up and close-out is much harder, as it requires ownership, planning and resources.

Discussion

RE requires the ability to identify drifts towards failure modes. In a complex and dynamic organisation where the potential for failure is seen to be continuously present, people need the authority and competence to identify potential failure modes and intervene where necessary. The majority of respondents believe people have this empowerment, although it is variable, and there is doubt that people may exercise this option for fear of retribution if they get it wrong.



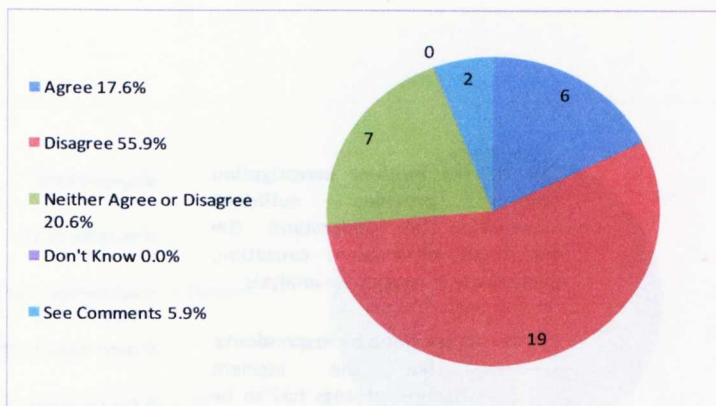
People within the organisation have sufficient understanding of what is actually being practised and this is consistent with what senior management believe is happening

Comments provided by respondents

- Alignment can improve, in particular, for *ad-hoc* subcontractors.
- Company-specific.
- Senior Management set clear direction, or believe they set clear direction. Clarity on what is actually required (clear guidance) is missing. The philosophy is clear, but without education, implementation will lag.
- Depends both on organisations and individuals. Buncefield is a prime example of failure of this. Procedures were poor and ignored, and there was no auditing of actual practices against procedures.
- Think there is a health difference. Mutual understanding of on and offshore wishes should be narrowed in the industry.
- What senior management believes may often have little relationship to what is actually going on.

Discussion

RE assumes that there is no difference between what is being practised and what management assumes is happening. This ensures that adequate resources are committed to maintaining suitable and sufficient controls over risks. However, the majority of respondents believe there is a difference between management understanding and actual practice. This can, for example, lead to misplaced confidence in safety performance and under-resourcing strategies to improve safety performance, which is a finding in some accident investigations such as Texas City (2005) and Deepwater Horizon.



The current incident investigation process provides sufficient information to understand the complexity of incident causation, particularly in root cause analysis

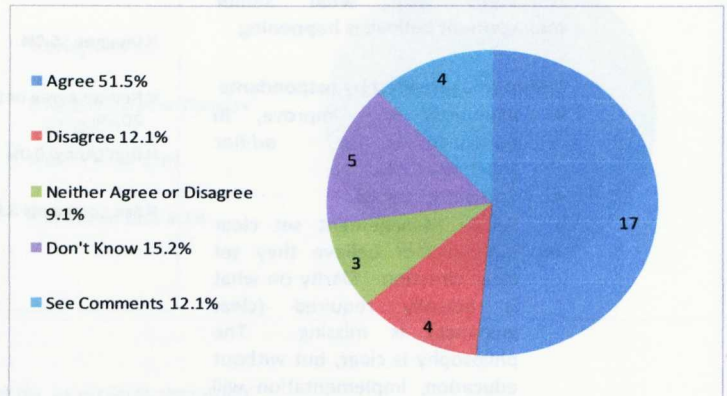
Comments provided by respondents

- Yes, but the incident investigation process has to be facilitated by competent people.
- Most companies in the O&G business seem to have good incident investigation processes.
- Not relevant.
- Most O&G operators have a comprehensive incident investigation process.

- There are various tools available for an investigation and the quality of the outcome of the investigation depends on the experience of the facilitator, and the knowledge and experience of the team.
- The processes are good but the application is often poor
- Company-specific.
- Depending on the nature and potential of the incident the investigation team is capable of doing so. Involvement from onshore safety consultants often makes investigation vague.
- The process has the potential. However, the application of the process is deficient.
- It requires very high level and independent discussions, as well as site investigation.

Discussion

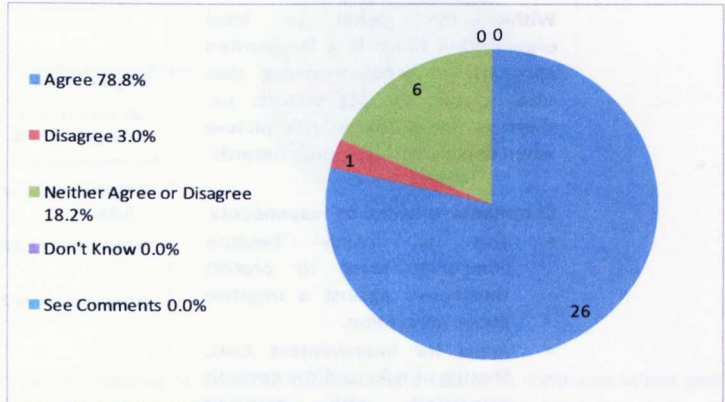
Re argues that current 'linear' accident causation models are not suitable to explain accidents in complex and dynamic industries and therefore, *de facto*, the true causes of accidents. Typically the root or underlying cause(s) may not be identified. Consequently, measures to prevent recurrence may also be missed. The majority of respondents believe that current linear models appear adequate, subject to the competence of investigation personnel, and effective implementation.



Safety defences start to erode when under pressure, e.g. controls may be compromised due to cost, schedule, production pressures, etc.

Comments provided by respondents

- A human factors issue.
- Except where there is a strong safety input at management level,; and even then it's a fight.
- I agree. Not in the company I work for but companies / clients we work with, often show this behaviour to our impression.



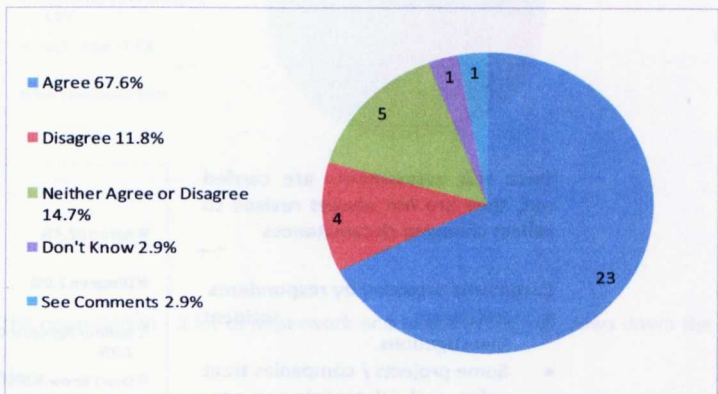
Discussion

This is similar to the previous question but specially examining whether safety defences can be compromised. RE states that there are a number of potential conflicts in organisations that are often difficult to reconcile, e.g. incompatible goals, and by implication they need to be resolved in a way that does not compromise safety. A significant percentage of respondents agree that, in this context, safety is often compromised, but it depends on factors such as company culture.

There is a perception within the organisation that when past safety performance has been good, this is taken as a reason for future confidence about the adequacy of current risk control practices

Comments provided by respondents

- Therefore it is necessary to also have a strong focus on near-misses and potentials.
- Please note this comment is common to all companies/organisations I have worked with until now.



- Past performance is often looked at and if it hasn't happened, confidence that it can't / won't is high this is despite the fact that the industry as a whole has major events with alarming regularity. It seems difficult for non-technical safety specialists to understand the reality of low probability catastrophic consequence events.

Discussion

RE states that companies who become complacent about future [safety] performance, and therefore the need to maintain effort and resources in this area, based on previous performance, may be vulnerable to increased risk. The majority of respondents agree this is the case. This is especially relevant in the case of major accidents where their absence is seen to be a good predictor for the future, despite the fact they are low likelihood but high consequence events.

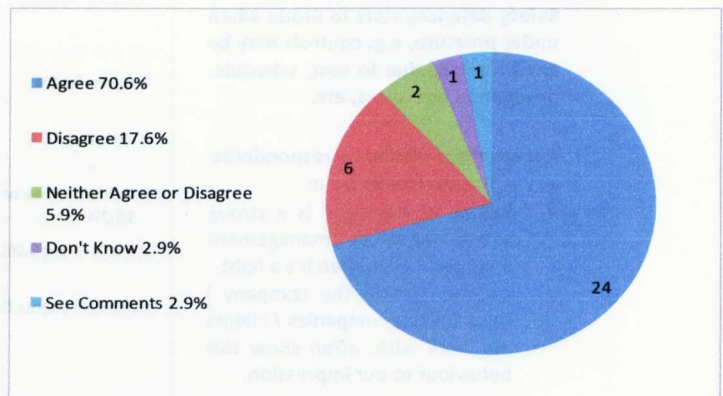
Within the global or local organisation there is a fragmented approach to problem-solving that often clouds the big picture, i.e. there is not a shared risk picture when dealing with common hazards

Comments provided by respondents

- This is mainly because companies want to protect themselves against a negative public perception.
- Areas for improvement exist. Sharing of risks and the controls associated with common hazards are shared reasonably well.
- Very much depends on the organisation.

Discussion

RE suggests that fragmented problem-solving devalues the safety management process, particularly in large organisations, where there are ample opportunities for sharing lessons learnt, benchmarking good/best practices, etc. and this can lead to duplicating errors or failures within an organisation. The majority agree that there is a fragmented approach, perhaps as a guard against external scrutiny.



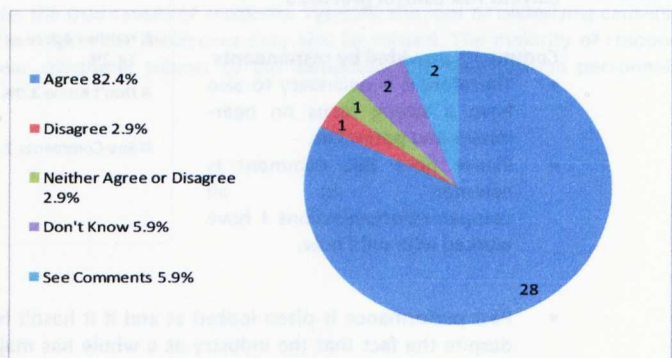
Once risk assessments are carried out, they are not always revised to reflect changing circumstances

Comments provided by respondents

- Reference Incident investigations.
- Some projects / companies treat safety and risk reports as a one-off, which are only of use in gaining regulatory approval.
- This is hardly ever done because of the additional costs involved.
- Very much depends on the organisation.
- HAZOPS and site changes (MoC) are frequently omitted.

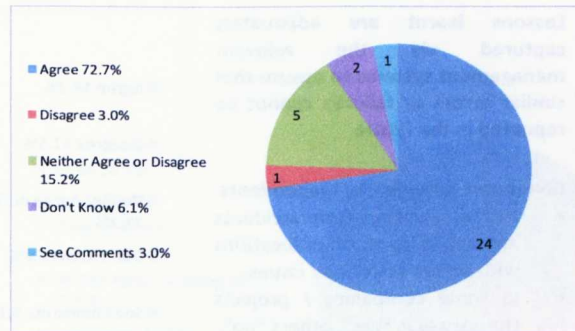
Discussion

RE argues that failure to manage risk leads to instability and drifts into failure modes, i.e. a lack of resilience against threats, etc. A significant percentage agrees that risk assessments are not always accurate, particularly where they might need to be revised following change.



There is often a breakdown in communications and coordination between disciplines and departments that may contribute to errors and failures

Comments provided by respondents
Very much depends on the organisation.



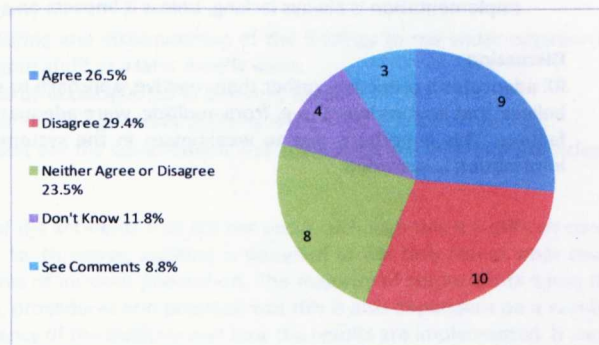
Discussion

RE indicates that one of the contributory factors leading to a lack of resilience is a failure in communications and coordination within an organisation. The majority agree that this is the case.

The organisation can respond flexibly and rapidly to changing demands, e.g. asset integrity issues

Comments provided by respondents

- See focus assets supported by engineering integrity.
- Organisation response to changing demands is reactive and usually happens as the result of an incident.
- Depends on the organisation/company.



- I suppose it depends on the size of the organisation - a lot of paperwork and bureaucracy just slows down the response.
- Very much depends on the organisation.
- The roll-out of new processes during a project life is always a challenge but the end point to be achieved must be agreed in time for the PSUA (Platform Start Up Audit).

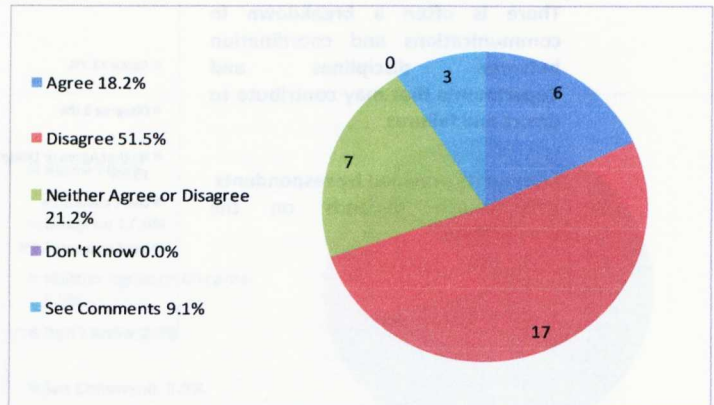
Discussion

RE requires that organisations have a buffering capacity to absorb change without negative consequences, and are sufficiently flexible to respond to perturbations without adverse outcomes. The response is almost equally divided but indicates that it is organisation-specific and that it could be hampered by the use of reactive indicators and bureaucracy.

Lessons learnt are adequately captured via the relevant management systems to ensure that similar errors or failures cannot be repeated in the future

Comments provided by respondents

- Not all learnings from incidents are picked up on other locations with similar activities / issues.
- In some companies / projects the answer is "yes", others "no".
- They are often identified but often not implemented.
- Depends on the organisation/company.
- Lessons are captured - but not always so that they are not repeated.
- Very much depends on the organisation.
- Lessons learnt are captured, but the mechanism for holding them and distilling the essence is fragmented. Very often vendor or contractor companies will sign up to providing feedback as part of their ISO process, but implementation is always lacking, unless it impacts on a manufacturing process.



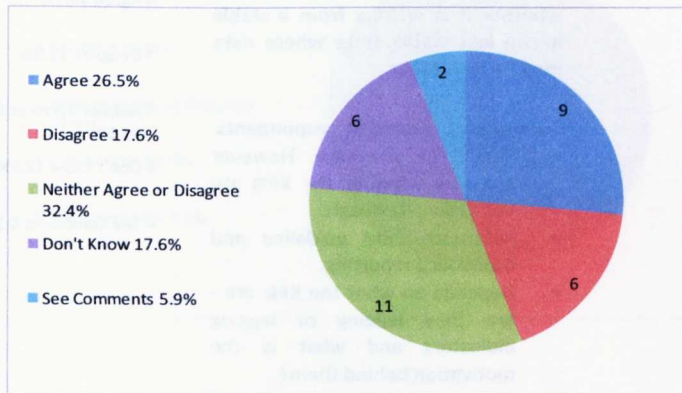
Discussion

RE advocates a proactive, rather than reactive, approach to safety management. The majority of respondents do not believe that lessons learnt, e.g. from auditing, were adequately captured to prevent recurrence of incidents or other failures. This is perhaps due to weaknesses in the systems that administer them, their implementation, or how information is cascaded.

There are sufficient detailed audits on the organisation to ensure that there is adequate compliance with safety policies, procedures and practices

Comments provided by respondents

- Number of audits often enough, quality of audits sometimes questionable.
- But the competences of auditors have to ensure, etc.
- I agree. However, continuous improvements are necessary.
- There can never be enough audits to ensure effective compliance with safety.
- Desktop, paper exercise audits are reasonably good but the implementation of the processes are in general poor.
- Depends on the organisation/company.
- There are sufficient audits - the sharing and dissemination of the findings to the wider organisation to enable improvement prior to having the same audit at a later date is weak.
- Although compliance can be seen to be accomplished in different ways.
- Very much depends on the organisation, but generally auditing is a budget line which gets cut.
- The process does have sufficient audit but the commitment and application are sometimes deficient.



Discussion

In RE it is stated that safety is the sum of the accidents that did not occur, although this is a difficult concept to apply any quantitative form of measurement to. However, auditing is designed to not only reveal what could go wrong, but also what is being done well, in terms of incident prevention. The majority of respondents agree that there are sufficient compliance audits for policies, procedures and practices but this is also dependent on a number of factors, i.e. the quality of the audit, the competency of the auditors and how the results are implemented. It should be noted that the question relates to compliance rather than an assessment of effectiveness, i.e. it assumes that the procedures being audited are fit-for-purpose and being effectively applied.

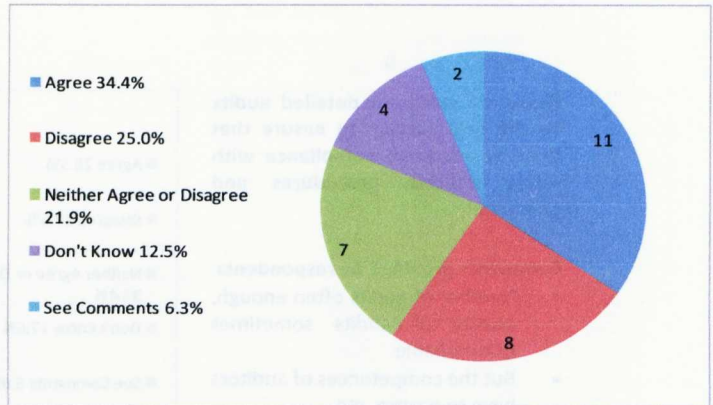
The organisation has sufficient proactive key performance indicators (KPIs) to help identify whether it is drifting from a stable into a less stable state where risks may be increasing

Comments provided by respondents

- Should be the case. However not sure whether the KPIs are defined well enough.
- Reference PRM guideline and dashboard reporting.
- Depends on what the KPIs are - are they leading or lagging indicators and what is the motivation behind them?
- There is a lack of consistency and understanding of proactive indicators.
- Depends on the organisation/company.
- Very much depends on the organisation; I would say it's about 50/50 in O&G operators I have worked with.
- This depends on the company / project and varies widely within the industry.

Discussion

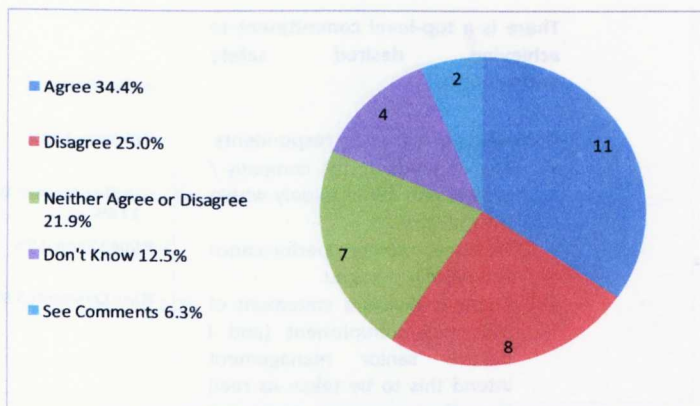
A key feature of RE is the ability to detect a drift into failure modes in order to take corrective action(s) before the drift escalates into an undesirable outcome. The majority of respondents agree that there are sufficient proactive KPIs to help identify this drift (trend). However, a high percentage disagrees on the basis that they may not be well enough defined, and often lack consistency and understanding. Perhaps this would make them less effective than, say, lagging/reactive KPIs.



There are always sufficient competent and experienced people with adequate resources, e.g. time and money, in place to consistently deliver asset integrity

Comments provided by respondents

- On occasions it is a struggle to get the experienced people to deliver asset integrity.
- Largely depends on which part of the world you work in. New Zealand, for example, has a very low population / resource pool.
- Not always.
- Asset integrity is usually undermanned, especially for ageing/ declining operations.



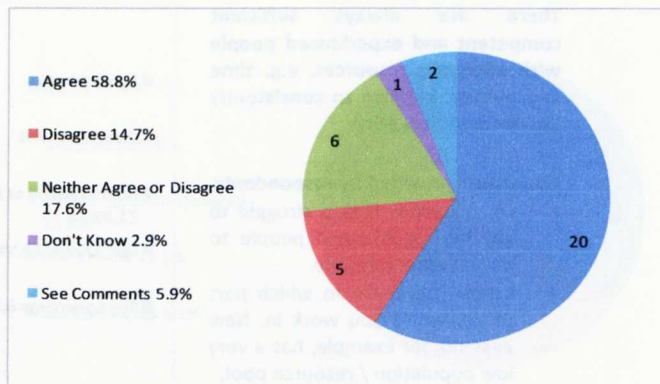
Discussion

The application of RE should ensure asset integrity in oil and gas installations. However, UK HSE research has shown that there is a lack of resilience in the systems that are designed to ensure asset integrity. This is supported by a significant percentage of respondents who disagree that there are always sufficient resources and competent personnel to deliver asset integrity. This may be especially true for normally unattended installations (in which case the risk to personnel is commensurately lower) and/or ageing installations, hence the recent UK HSE Key Programme campaigns.

There is a top-level commitment to achieving desired safety performance

Comments provided by respondents

- This depends on the company / project and varies widely within the industry.
- Disagree, safety performance actively discouraged.
- There is always a statement of top level commitment (and I believe senior management intend this to be taken as real) but the message does not always get through because of a perception that production is more important.



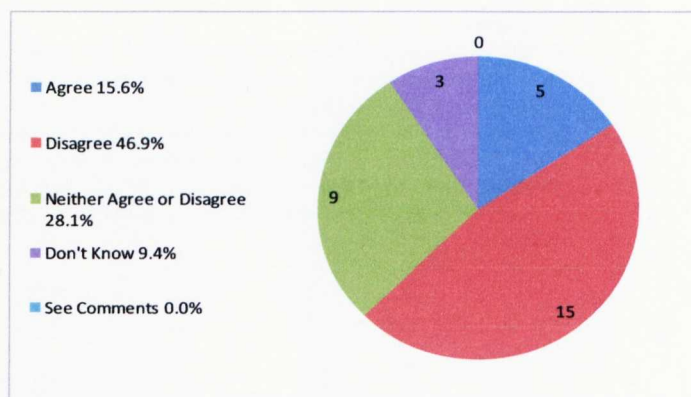
Discussion

RE considers that safety performance is related to the commitment of senior/top management and that poor or unsustained levels of commitment contribute to a lack of resilience. Most respondents agree that there is a top management commitment to safety but their intent can be diluted as it filters down through the various layers of the organisation, or the commitment is subject to financial constraints, or it is simply management rhetoric to satisfy stakeholders.

To achieve the desired level of safety performance, the organisation always proactively commits appropriate resources, e.g. money, people and time

Comments provided by respondents

- This depends on the company / project and varies widely within the industry.
- Small companies are unable to financially support the level of safety as much as larger companies.
- Not always.
- In budget terms, safety is always an 'unnecessary' cost. Occupational safety tends to get the resources it requires; major hazard safety may not.



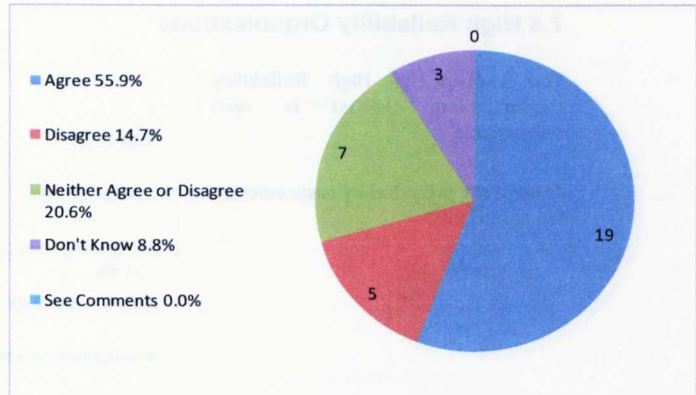
Discussion

This question examines the link between safety performance and resource allocation. Suitable and sufficient resources are needed to obtain desired safety performance and this includes the means to implement RE. The majority disagree that there are sufficient resources to meet desired safety performance, particularly for smaller companies, and in the prevention of major accidents.

There is a 'Just Culture' in the organisation that encourages reporting of incidents but does not accept negligent behaviours

Comments provided by respondents

- Inherent to Life Saving Rules.
- This depends on the company / project and varies widely within the industry.
- Some do, some don't.
- Depends on the organisation/company.
- True for all the operators I have worked with.



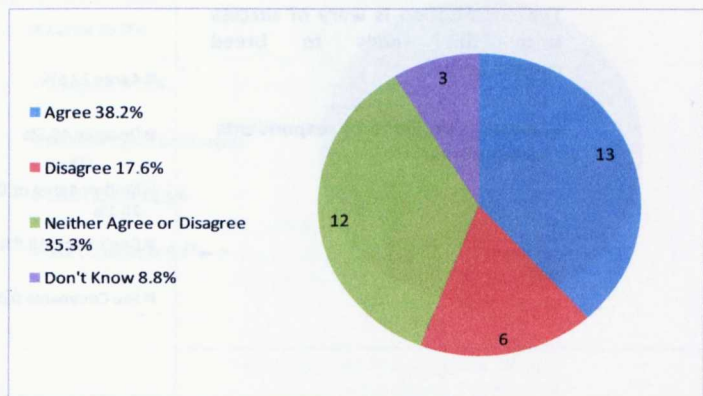
Discussion

RE states that a 'just culture' encourages the reporting of incidents but does not accept negligent behaviours. Incident reporting is necessary to understand both the immediate and root causes of incidents in order to develop improvement and preventative strategies. However, negligent behaviour cannot be tolerated as it exposes people to unnecessary risk, e.g. ignoring procedures. The majority of respondents agree that there is a 'just culture'.

There is a learning culture where there is no denial of adverse events but these are seen as positive and contribute to improvement

Comments provided by respondents

- This depends on the company / project and varies widely within the industry.
- Depends on the organisation/company.
- This is often counteracted by the need to report KPIs - i.e. potentially major incidents are downgraded in the reporting system to meet KPIs and therefore do not get the investigation or publicity that would be most beneficial.



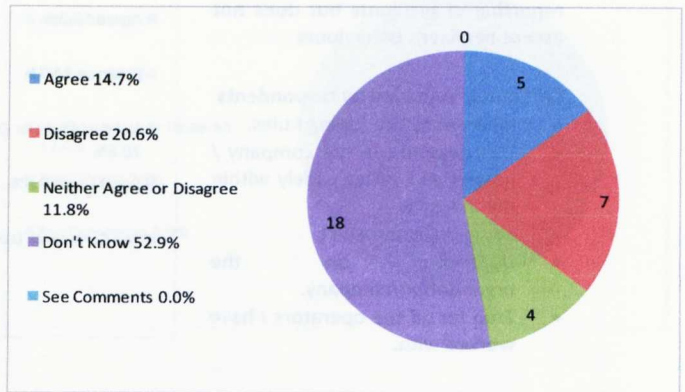
Discussion

One of the seven themes present in a highly resilient organisation (the others are discussed in the preceding questions) is the need to learn from all adverse events. Therefore, the reporting of any incident is seen as positive as lessons can be learnt and improvements made. Most respondents agree that there is a learning culture in the industry but serious events may be 'downgraded' because of reputational implications.

7.6 High Reliability Organisations

The concept of High Reliability Organisations (HROs) is well understood

Comments provided by respondents
No comments.

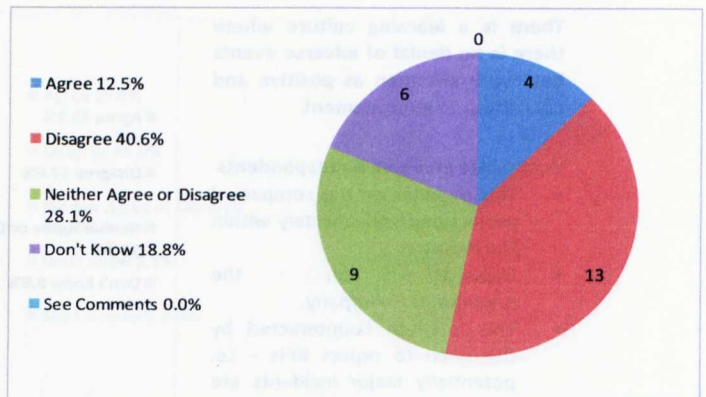


Discussion

The questionnaire was predominantly aimed at experienced and qualified safety practitioners who help establish the means of improving safety performance. A large percentage of respondents, 73.5%, the sum of those who don't know and those who disagree, are uncertain about whether the concept of HRO is well understood. This is a similar figure to that for RE.

The organisation is wary of success since this tends to breed complacency

Comments provided by respondents
No comments.



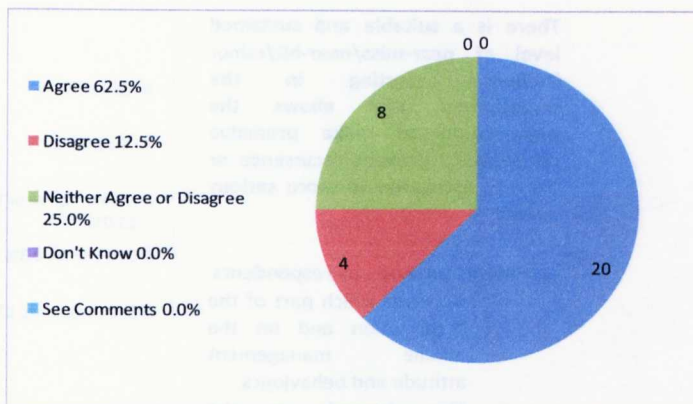
Discussion

Processes in HRO focus on failures rather than success and have a state of 'mindfulness' that maintains constant vigilance on performance. A large percentage disagree that the organisation is wary of success. This is a feature identified in the Texas City and Deepwater Horizon investigations, that the lack of 'significant' incidents demonstrated effective safety management, etc.

Even minor incidents are treated as evidence of a more serious, underlying, problem, and these are considered as an early warning signal to take decisive action

Comments provided by respondents

- This depends on the company / project and varies widely within the industry.
- Some organisations have a system for reviewing repeated minor incidents; or identifying minor incidents which had the potential to be major incidents. Most minor incidents receive little attention.



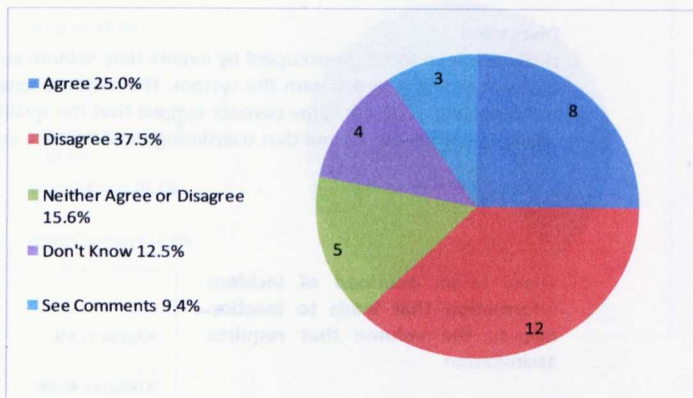
Discussion

In HROs, small errors are seen as evidence of a potentially more serious situation. This triggers a response in HROs that might be ignored elsewhere. The majority agree that even minor incidents are treated seriously.

There is an over-simplification of incident information generated in the organisation that could result in the loss of some vital data and/or the information that is available is not processed effectively

Comments provided by respondents

- Sometimes, not ALWAYS!!
- Statistical reports have to be simplified. This does lead to loss of detail which can only be retrieved if people read the underlying incident reports.



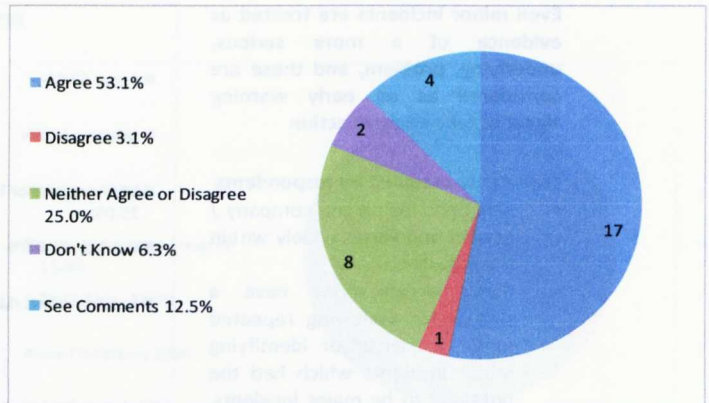
Discussion

HROs have a pool of people who can commit to ensure that there is no oversimplification and therefore loss of vital data that could be used to prevent the next incident. Most respondents disagree that oversimplification exists.

There is a suitable and sustained level of near-miss/near-hit/minor incident reporting in the organisation that allows the organisation to make proactive decisions to prevent recurrence or prevent escalation to more serious events

Comments provided by respondents

- Depends which part of the organisation and on the middle management attitude and behaviours.
- This depends on the company / project and varies widely within the industry.
- Agree that organisations have systems in place and expectations of reporting, but quality of reporting is often very poor (hard to get at root causes from descriptions), and amount of data can 'flood' the system.
- There is a suitable level of reporting and the organisation has the data to make proactive decisions; it just doesn't have the learning culture to do so.
- There is incident reporting but this does not always prevent recurrence.
- True within some, but not all, operators.
- Reporting level is very high, perhaps too high, but not convinced that this is allowing proactive decisions to prevent re-occurrence.



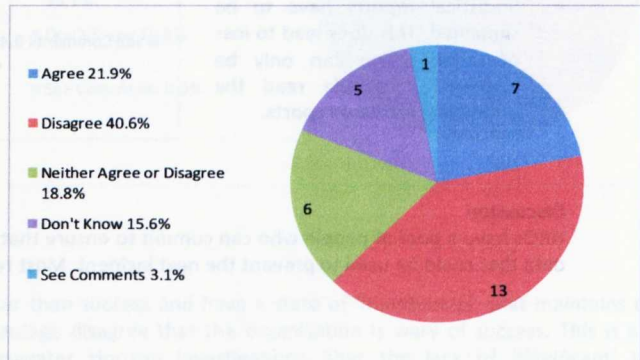
Discussion

HROs are seen to be preoccupied by events they seldom see and therefore even the smallest error could be a signal that something is wrong with the system. The majority agrees that there is an adequate level of near-miss (or near-hit) reporting although some caveats suggest that the quality of reporting is very poor (and therefore diminishes the ability to learn lessons) and that translating these lessons into proactive strategies may also be poor.

There is an overload of incident information that leads to inaction due to the volume that requires assimilation

Comments provided by respondents

- Most companies capture the 'big picture' of incidents with consequences, even if they don't translate them into frequencies
- Possible, but not in my experience.



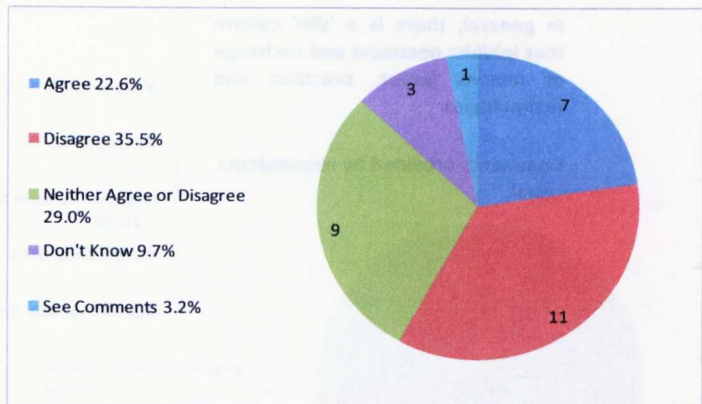
Discussion

In HROs, data is king since this allows informed decisions to be made. Most respondents disagree that there is an overload of information but it is uncertain whether the data that is available is suitable and sufficient, and is managed in a way that ensures a fast and appropriate reaction.

There are sufficient competent and experienced people in the organisation to maintain consistency and continuity during periods of change

Comments provided by respondents

- The OpCo does a lot of complex work to assure HSE competencies. However, I'm not sure how consistent or objective it is.
- Becoming a bigger issue.
- Due to frequent job rotations, some knowledge is just lost.
- Depends on the operator.



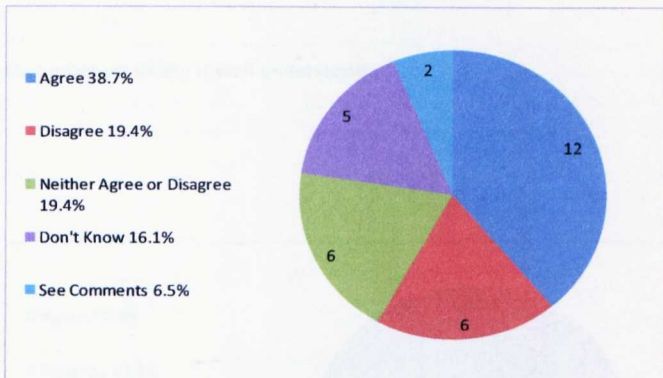
Discussion

HROs have a history of safe operations and one of the characteristics of a HRO is that it must act as a single entity rather than the fragmented behaviours of many. Consequently, personnel need to be able to provide the consistency and continuity to achieve this objective. The majority disagree that there are sufficient personnel to provide continuity and consistency.

Job rotation and using employees with non-typical job experience provides greater depth and more challenges in decision-making thereby allowing the organisation to cope better with the unexpected

Comments provided by respondents

- Agree but critical core of knowledge should be assured (not always the case).
- Depends on the position and the person. It is useful for graduates to spend some time in HSE as part of their development programmes.
- Job rotation can mean that valuable experience is lost. But it can also bring a 'fresh pair of eyes'.

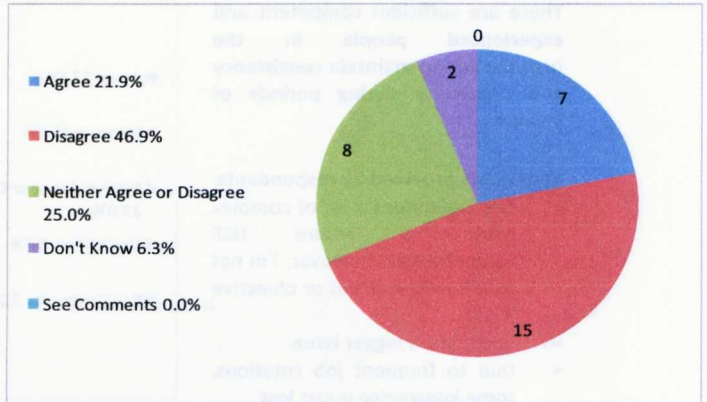


Discussion

HROs need to be able to cope with both the expected and unexpected. Therefore personnel within an organisation should have a wide range of experience and competencies to provide depth and understanding of situations, to be able to understand what is happening and why and therefore take timely and appropriate corrective action(s). The majority of respondents agree with the need for non-typical job experience, greater depth and more challenges in decision-making.

In general, there is a 'silo' culture that inhibits openness and exchange of lessons learnt, practices and technologies

Comments provided by respondents
Usual.



Discussion

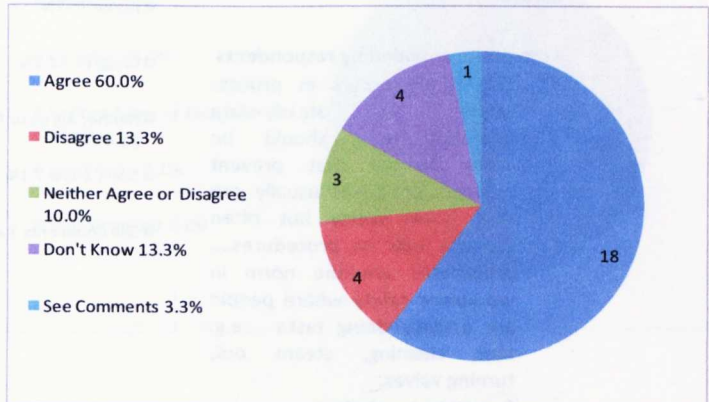
In HROs, silo mentality is discouraged and openness and awareness of the big picture endorsed to improve the ability to capture lessons learnt and ways to prevent failure. About half of the respondents disagree that there is a silo mentality.

7.7 Inherent Safety

The concept of Inherent Safety is well understood.

Comments provided by respondents

- It is understood but often ignored as the higher- placed barriers are more expensive, so discounted as impractical (e.g. fin fan coolers selected in preference to shell & tube in sour service).
- This is correct for major projects. However, small projects do not always apply IDS (Inherently Safer Design).
- Well-understood but not always well-implemented.



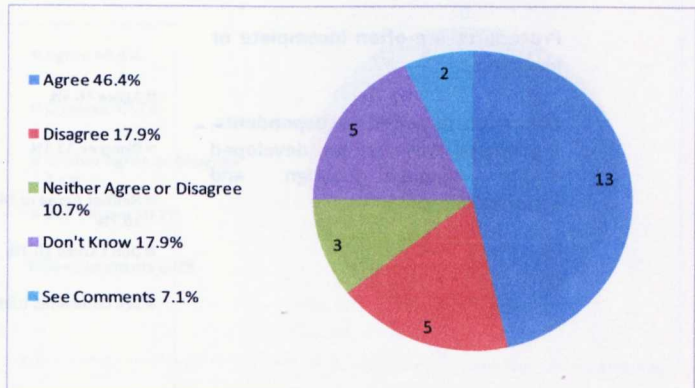
Discussion

A large percentage of respondents agree that inherent safety is well understood.

The current risk control hierarchy uses the following approach consistently in the following order:
a) Risk reduction by inherent safety
b) Risk reduction by basic process control
c) Risk reduction by pre-alarms
d) Risk reduction by Instrumented Protective Function (IPF)
e) Risk reduction by mechanical devices
f) Risk reduction by other means

Comments provided by respondents

- They are in part, but not necessarily in this order.
- Our OpCo tries to do this, other operators less so.
- Disagree with the hierarchy. An alarm (alone) does not reduce risk. It is really 'operator monitoring and intervention'.



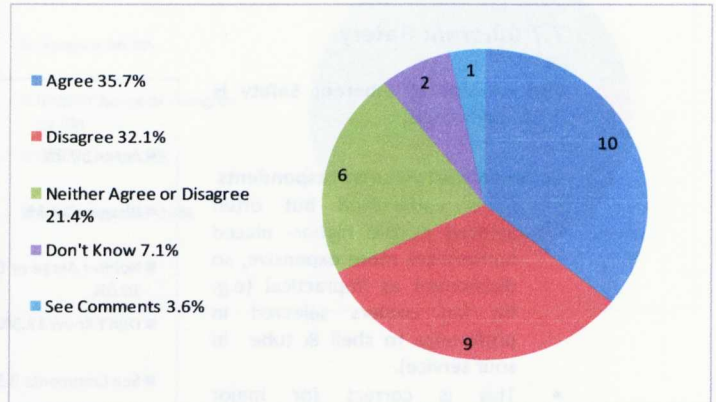
Discussion

The risk control hierarchy is designed to maximise the control and mitigations over the lifecycle of a development. Hence inherent safety avoids controls, such as procedures or active controls that are more susceptible to error. About half agree that this hierarchy is applied, or at least that the concept is.

Often designs are not inherently safe but tend to rely on procedural control

Comments provided by respondents

- This rarely occurs in process safety for steady-state operation...there should be other devices that prevent failures....processes usually can shut down safely but often startups rely on procedures.... procedures are the norm in workplace safety where people are actively doing taskse.g. tank cleaning, steam out, turning valves.
- Sometimes, not often.
- The major hazards are generally well-handled, but inherent safety of lesser hazards is less well controlled.



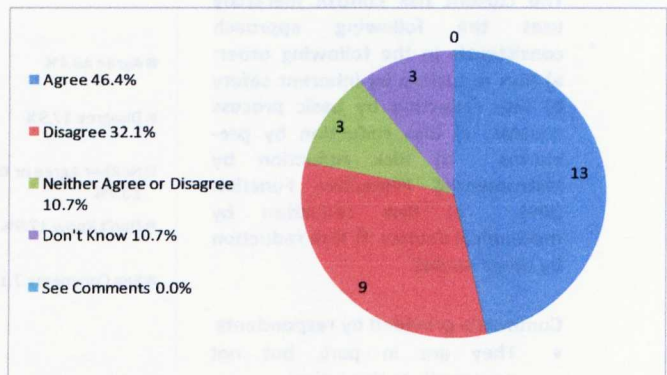
Discussion

In the absence of factors such as safety KPIs in design, robust auditing of design principles, cost and schedule priorities, it is possible, and in many cases seen to be legitimate, to design systems that rely solely on procedures as a means of system integrity. No firm conclusions are drawn either way.

Procedures are often incomplete or inaccurate

Comments provided by respondents

Procedures tend to be developed during detailed design and commissioning.



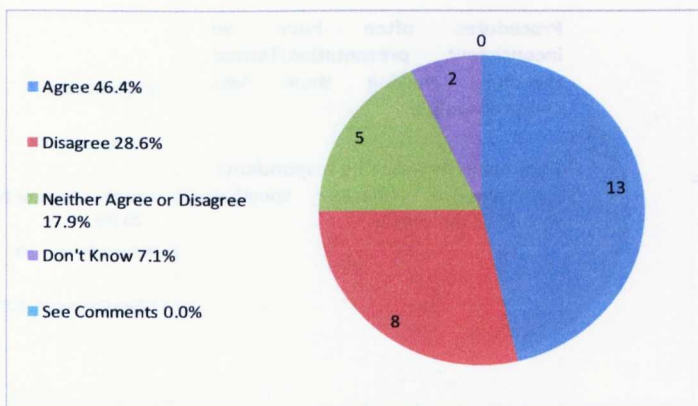
Discussion

If there is a significant reliance on procedures to ensure asset integrity and personal protection it is incumbent, as a minimum, that the procedures are accurate, complete and understood, etc. The majority agree that procedures are often incomplete or inaccurate.

Procedures often do not have sufficient detail e.g. that considers lessons learnt, the experience of users and their specific responsibilities

Comments provided by respondents

- Work Instructions are more specific.
- True but procedures often have too much irrelevant detail (for fear of leaving something out).
- Procedures typically include experience and key steps (higher degree of risk) highlighted. Lessons learnt are not often documented.



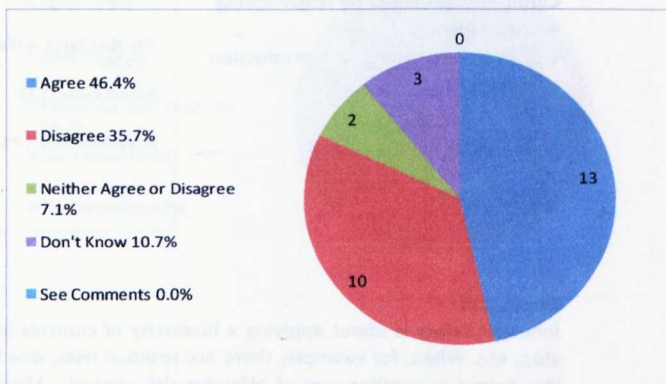
Discussion

Procedures should capture lessons learnt to avoid any repetition of previous errors or failures, particularly for new systems and/or personnel that are going through the learning curve. The majority agree that procedures do not have sufficient detail that adequately captures lessons learnt. In this context it is always seen to be a compromise, in that capturing all relevant lessons learnt may result in voluminous procedures, which may be self-defeating, while concise procedures that are easily read and understood may lack important safety information. There are different forms of procedures (e.g. written instructions) that may require different categories of compliance, e.g. statutory requirements and some company standards may be mandatory, while some others are intended for guidance only.

Procedures are often not concise and contain information that does not contribute to work performance

Comments provided by respondents

No comments.

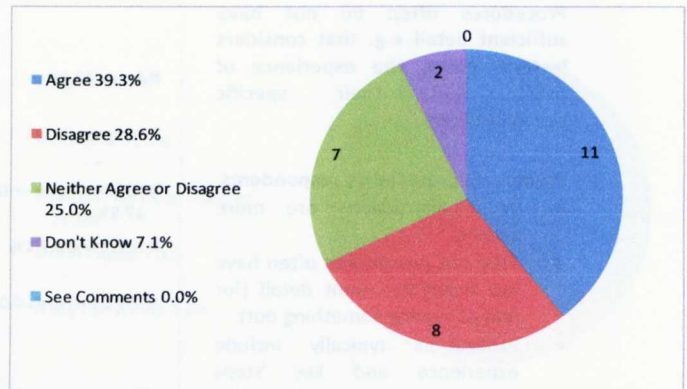


Discussion

Procedures may contain irrelevant information, making their implementation more difficult. Inaccurate and irrelevant aspects of procedures are more likely to cause people to ignore or bypass them. Most agree that procedures often contain information that does not contribute to work or safety performance.

Procedures often have an inconsistent presentation/format therefore making them less comprehensible

Comments provided by respondents
Generally, an operator specifies format at the outset.



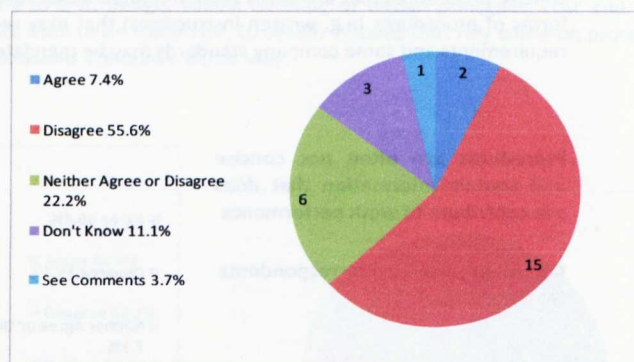
Discussion

Procedures contain the written instructions about how to execute tasks. The procedures need to be understandable, and should be written so that what needs to be done can be easily followed by all users. Inconsistent styles and formats may cause confusion and error. About two-fifths agree that procedures are often inconsistent.

Hydrocarbon or other hazardous processes are always designed to minimise the maintenance burden

Comments provided by respondents

- Not always.
- We are not a production platform.



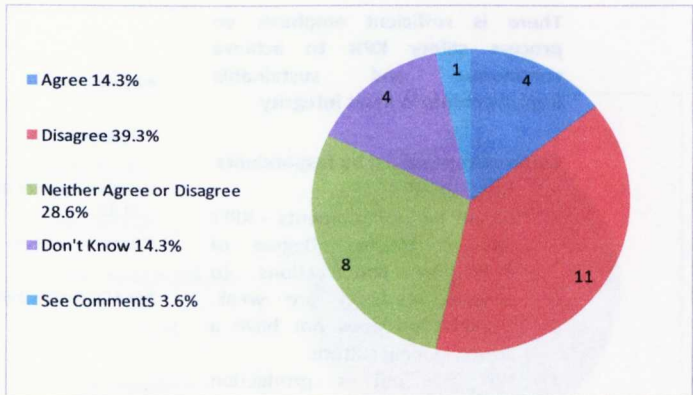
Discussion

Inherent safety is about applying a hierarchy of controls in a sequential way, so eliminating the hazard is the first step, etc. When, for example, there are residual risks, due to the presence of hydrocarbons, removing people from the hazard is another way of effective risk control. Most respondents disagree that hydrocarbon processes are designed to minimise the intervention of people.

Hydrocarbon or other hazardous processes are always designed to minimise intrusive instrumentation

Comments provided by respondents

- Not always.
- We are not a production platform.



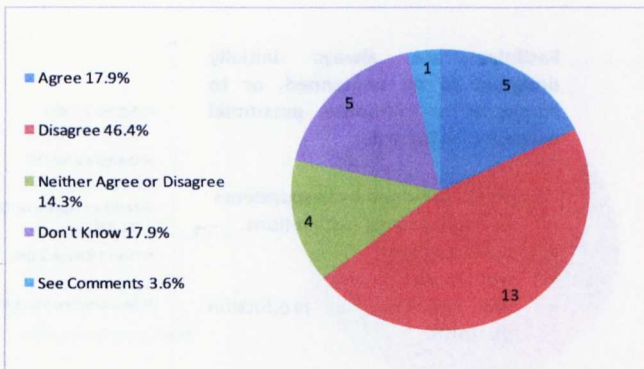
Discussion

An inherently safe design would ensure that the design, maintenance and operating parameters of a process could never be exceeded beyond safe limits by internal or external events, in either normal or abnormal conditions. Intrusive instrumentation often provides a 'weak' point in the system since it is generally less robust than the process. Where this is not possible, non-intrusive instrumentation can often be used to manage the process within prescribed limits. About two-thirds disagree that process design minimises the need for instrumentation.

Hydrocarbon or other hazardous processes are always designed to minimise piping joints

Comments provided by respondents

- Not always.
- We are not a production platform.



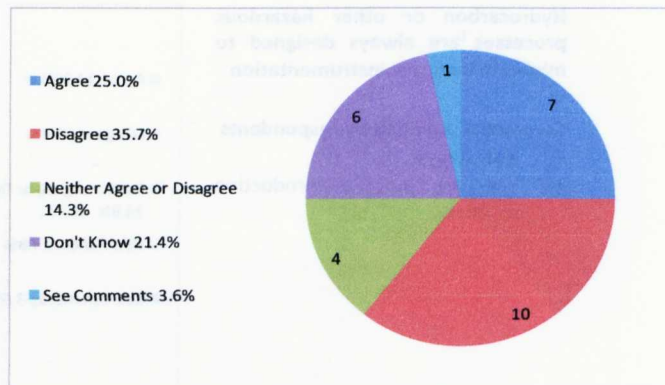
Discussion

From a quantitative risk perspective, the more piping joints there are the more the potential leak paths and the greater the risk of a release. It is often possible to minimise joints (e.g. flanges) by providing welded connections, although this may make installation of the piping more difficult. However, welded joints result in a greater cost compared with flanged connections. Most disagree that piping joints are minimised.

There is sufficient emphasis on process safety KPIs to achieve continuous and sustainable improvements in asset integrity

Comments provided by respondents

- Just started.
- As per earlier comments - KPI's data is tracked. Degree of evaluation and actions to address learnings are weak. Organisation does not have a strong leaning culture.
- We are not a production platform.



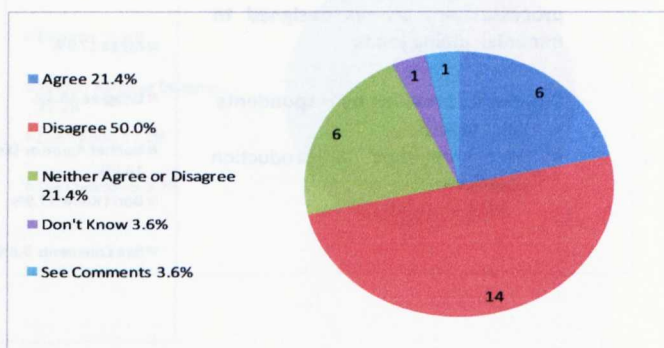
Discussion

Historically, KPIs have focused around preventing injuries to people. In recent years process safety has gained more prominence following disasters such as Piper Alpha (1988), Texas City (2005) and Deepwater Horizon (2010). These major accidents were initially caused by process-related safety failures which are more likely to result in a major accident than an occupational incident. About a third disagree that there is sufficient emphasis given to process safety KPIs.

Facilities are always initially designed to be unmanned, or to eliminate or minimise personnel exposure to hazards

Comments provided by respondents

- Reference aging installations.
- But many are.
- Not always.
- We are not a production platform.



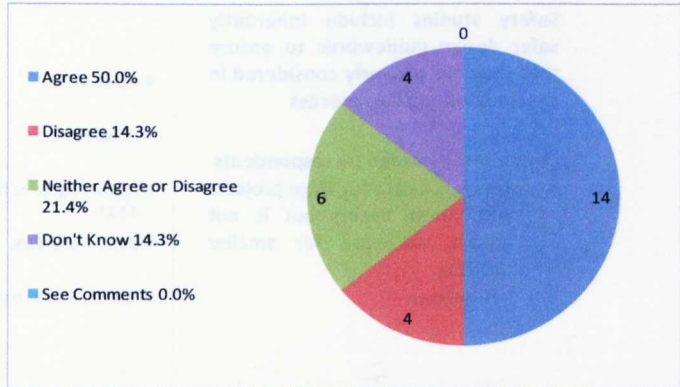
Discussion

Removing people from hazards means they cannot be hurt. There are technologies and techniques for managing oil and gas facilities remotely, although not continuously without any maintenance or breakdown interventions. About half agree that facilities are not generally designed to be unmanned since interruptions/breakdowns, and any associated stoppage of production, can outweigh the cost of manned installations. Furthermore, there may be reliability issues associated with remotely controlled facilities.

Designs always favour passive rather than active control systems

Comments provided by respondents

- Use of "always" is a problem.
- Emergency Shutdown (ESD) systems are always the major hazard primary control.



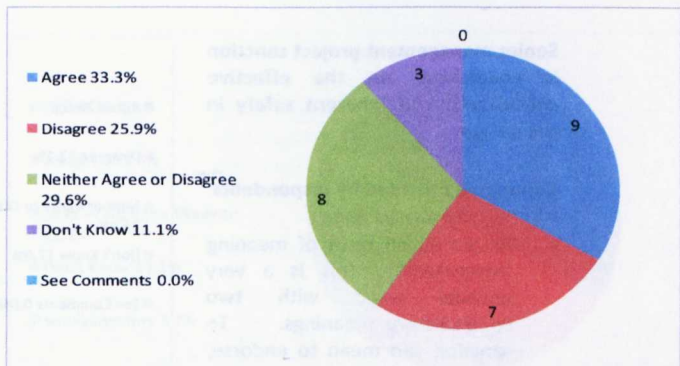
Discussion

Passive protection is inherently reliable as there are few parts that could fail, e.g. passive fire protection where coatings are applied to vulnerable surfaces to protect structures (and thereby prevent premature failure that could affect the safety of people) against thermal effects. In comparison water curtains require firewater pumps and drivers, etc. About half agree that providing passive control systems is preferred to active forms of protection.

Maximising inherent safety in design is seen as a cost-effective approach when considered over the lifecycle of the development (even if this requires greater initial investment)

Comments provided by respondents

- But not always done.
- Sometimes.
- Not often.



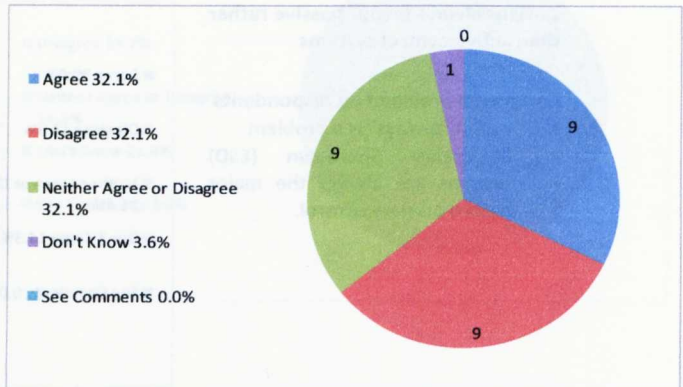
Discussion

The greatest opportunity to shape lifecycle safety performance is during design when changes are readily accommodated and can be relatively cheaply applied. As a development progresses through the lifecycle phases, introducing the same principles of inherent safety becomes progressively more expensive (when normalised for comparison), and therefore lower orders of control are often applied. About a third agree that maximising inherent safety in design is a cost-effective approach.

Safety studies include inherently safer design guidewords to ensure that they are properly considered in the decision-making process

Comments provided by respondents

- This is the case for large projects with some clients but is not always the case for smaller projects.
- Sometimes.



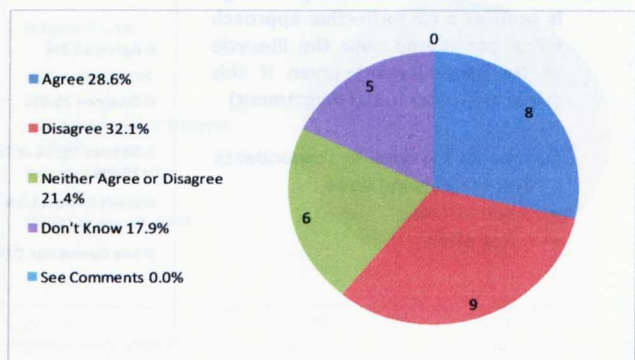
Discussion

Aviation, aeronautics, and product manufacturing have come to rely heavily on checklists to reduce human error. The checklist is an important tool in error management across all these fields, contributing significantly to reductions in the risk of costly mistakes and improving overall outcomes. If inherent safety is not part of a designer's checklist then its application may well be missed. There is no firm conclusion either way about the use of checklists containing inherent safety.

Senior management project sanction is conditional on the effective consideration of inherent safety in the design

Comments provided by respondents

- But not always done.
- Answered on basis of meaning 'agreement'. This is a very unusual word with two contradictory meanings. To sanction can mean to endorse, to ratify or to approve but confusingly, it can also mean to punish.

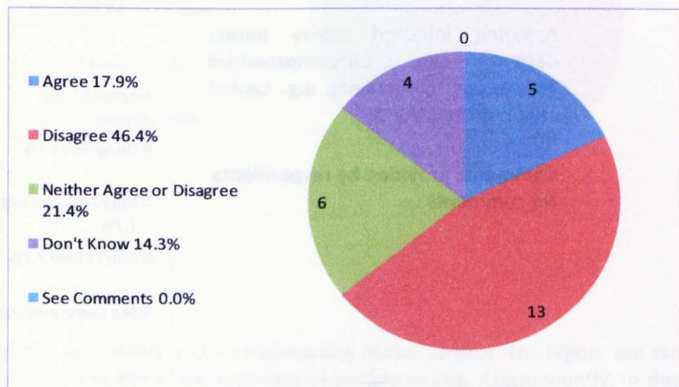


Discussion

Project assurance processes often involve gates where an assessment is made about the viability of a project, and if sufficient and suitable work has been done, to justify moving onto the next phase. One of the conditions within the assurance process could be the degree of inherent safety in the design. About a third disagree that project sanction is conditional on the effective consideration of inherent safety in the design.

True lifecycle costs of projects (not just the cost of design, fabrication, installation and commissioning) are taken into account when assessing risks to enumerate the benefits of inherently safer design

Comments provided by respondents
No comments.



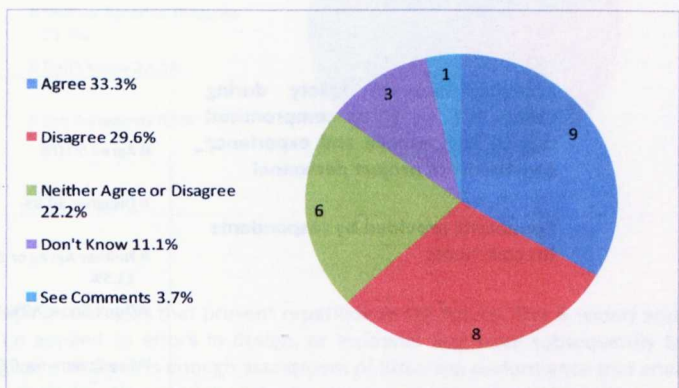
Discussion

While it may be difficult to determine overall lifecycle costs, estimates can often be made by using data from previous comparable projects. The benefits of higher initial capital expenditure (CAPEX) to improve the implementation of inherent safety in a design could more readily be justified if it was evaluated in relation to overall lifecycle costs. Absolute figures may not be necessary as the analysis would be to compare designs. About half disagree that lifecycle costs are taken into account.

Concept selection is based on the ranking of various options with transparent safety criteria including the application of inherently safer design principles

Comments provided by respondents

- Often not enough detail for transparency during concept. Safety aspects are part of the process though.
- Too many examples where it wasn't (OpCo included).
- Application of inherently safer design not often transparent.
- Sometimes; safety criteria may be transparent, but inherent safety by itself may not be.

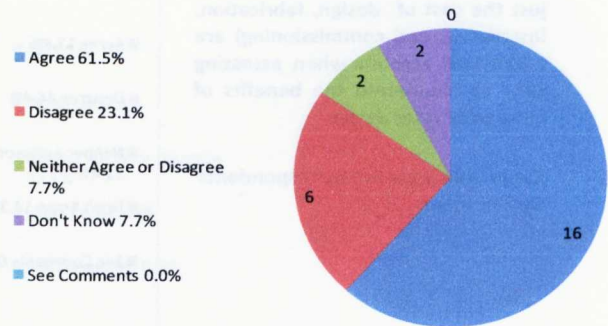


Discussion

Part of an ALARP decision is to look at all design options available in order to select the one that optimises project specifications when considered against criteria such as finance, operations, maintenance, HSE and schedule, etc. Each of these categories is normally given a weighting to reflect its relative importance when compared to other categories. About a third agree that concept selection is based on the ranking of various options with transparent safety criteria, including the application of inherently safer design principles

Applying inherent safety during design is likely to be compromised due to cost constraints, e.g. capital expenditure (CAPEX)

Comments provided by respondents
No comments

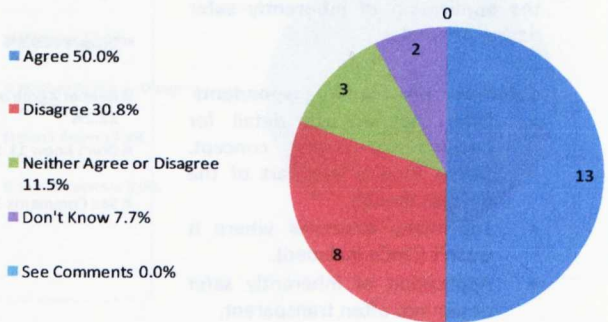


Discussion

Oil and gas companies have little influence on oil and gas prices, and therefore to achieve suitable margins they focus on cost control. Consequently, there is an endemic cost culture within oil and gas companies that competes with the need to adequately fund safety improvements. Therefore, irrespective of the evidence that it can be cost-effective to include inherent safety in a design, there might be an overwhelming resistance if there is no statutory or company mandate that enforces its application. About two-thirds agree that application of inherent safety is likely to be compromised due to cost constraints.

Applying inherent safety during design is likely to be compromised due to competency and experience constraints of project personnel

Comments provided by respondents
No comments

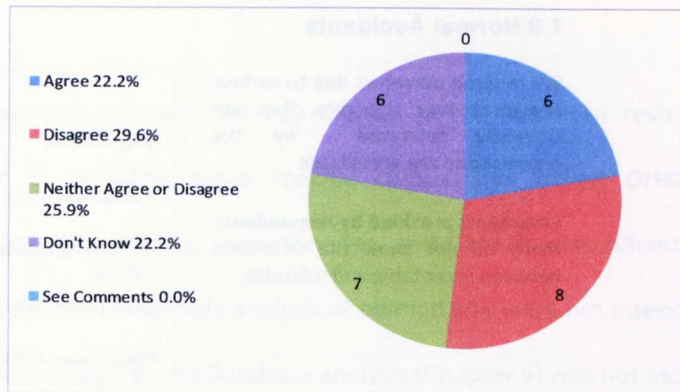


Discussion

If project personnel do not have the necessary competencies and experience to apply inherent safety during design then it is less likely to happen. About half agree that project personnel, not just the safety professionals, may not have the requisite skills to apply inherent safety.

In the design of critical combinations and complex integrations of engineered systems, the design criteria for reliability, availability and maintainability (RAM analysis) is identified as a KPI to ensure desired design integrity, not just what can be achieved, but what should be assured

Comments provided by respondents
No comments

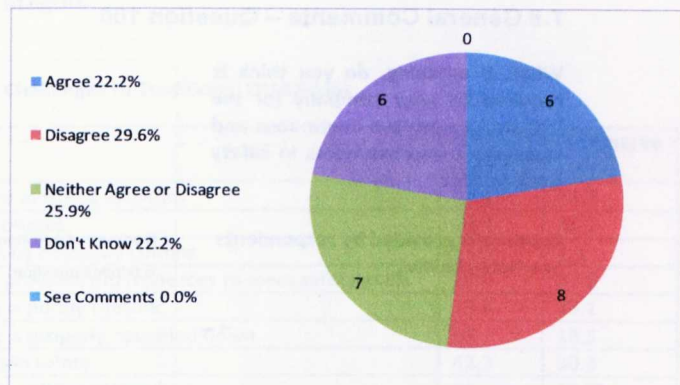


Discussion

Processes can be designed to meet reliability, availability and maintainability (RAM) targets. The higher the target, the less demand for breakdown interventions, and therefore exposure of people to risk. Consequently, in design, there should be a KPI against which the project design is assessed, and the project sanctioned, through an assurance procedure that meets production and safety objectives. About a third disagree that RAM KPIs are set to satisfy this requirement.

Project teams always study past incidents associated with designs to minimise the potential of error/failure (hardware, software and human) by eliminating or mitigating the causes (immediate/root) of past problems.

Comments provided by respondents
Not 'always'.



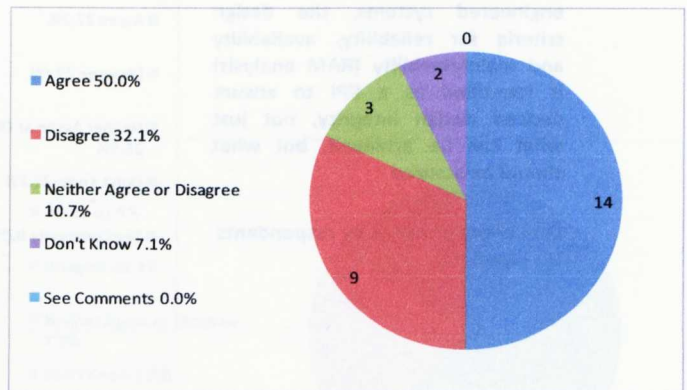
Discussion

Learning from the past can help in developing strategies that prevent repetition in the future. This is widely applied to occupational safety but should also be applied to errors in design, or incidents that have subsequently been caused by design failures. About a fifth agree that there is enough assessment of historical performance that enables a design team to reduce potential failures in design. Irrespective of the resources committed to achieve safety goals, it is argued by Charles Perrow, that given factors such as tight-coupling, and complexity of plant design, accidents will happen and therefore are 'normal'.

7.8 Normal Accidents

We mislead ourselves due to various pressures that the risks that are currently tolerated by the organisation are acceptable

Comments provided by respondents
Many do not know the difference between acceptable and tolerable.



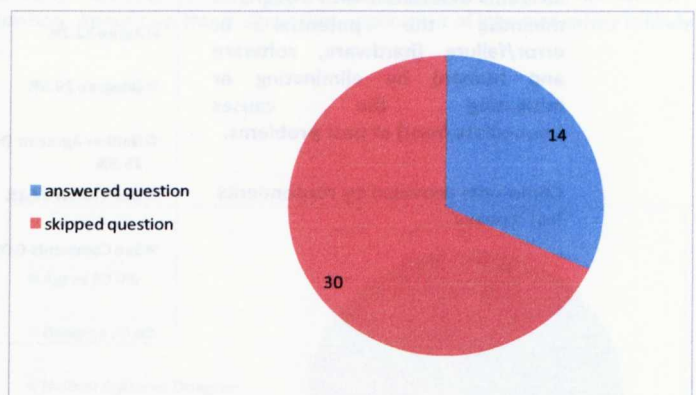
Discussion

In normal accident theory it is proposed that given cost, schedule, production and other influences, the residual risks within an operation are 'part of the job' or an inherent feature of the company's activities for which little can be done. Consequently they are generally accepted by the workforce, e.g. not challenged, and therefore may remain higher than they need to be. About half agree that this is the case.

7.9 General Comments – Question 100

What, if anything, do you think is required by your company (or the industry) to achieve continuous and sustainable improvements in safety performance?

Comments provided by respondents
See Notes below.



Discussion

No additional comments were made by 56% of respondents.

General Discussion Open Comments (Question 100)

The comments repeated or emphasised previous information contained and since they offer no added value they have been excluded for expediency.

7.10 Summary

The questions were based on general principles for key themes in the literature review for Traditional OH&S-MSs (Chapter 2) including some specific components of an OH&S-MS, Challenges to Traditional OH&S-MSs (Chapter 3), some theories, and Case Studies (Chapter 5). The questions were selected to provide a reasonable analysis of opinion and were not intended to be a comprehensive analysis of each category. The Database analysis (Chapter 6) was not included in the questionnaire as it was specific and unique to this research. The results and discussion are summarised below. For simplicity, the tables do not include response options of 'Neither agree or disagree' or 'Don't know'.

7.10.1 Traditional OH&S-MSs

There were 14 questions in this category.

Table 18 Questionnaire Traditional and Challenges to Traditional OH&S-MSs

Question summary	% Agree	% Disagree
OH&S-MS is managed same as other core business activities	48.1	33.3
OH&S-MS lacks definition for all project phases	22.2	48.1
Money and resources for safety is driven by company culture	55.6	7.4
The safety culture ensures the company provides the resources to meet safety goals	29.6	37.0
Senior management safety commitment is purely rhetoric	29.6	48.1
Senior management safety commitment is properly cascaded down	63	18.5
There is effective workforce involvement in safety	42.3	30.3
Lessons from Piper Alpha have been adequately captured	51	18.5
Future challenges means more vulnerability to major accidents	48.1	14.8
Current approach to OH&S-MS allows for continuous and sustainable safety improvement	30.8	23.1
The regulator is adequately resourced	14.8	51.9
The regulator provides authoritative advice and is available	23.1	53.8
The regulator uses its power of enforcement to deter poor risk management	44.4	18.5
Goal-setting legislative regime has helped improve safety performance	61.5	3.8

In terms of effective implementation of an OH&S-MS there is some uncertainty but there is strong agreement that safety culture is a dominant driver affecting safety performance (in agreement s2.3.3). There is also strong agreement that there is a senior management commitment to deliver safety goals, that lessons from Piper Alpha have been adequately captured (somewhat contrary to

the findings in s5.9) and that a goal-setting legislative safety regime has improved safety performance, although there is no evidence to support this view. There is reasonable agreement that the regulator is ineffective and this supports the conclusion from the four case studies, s5.9)

7.10.2 Project and Risk Management

There were 19 questions in this category (Question 20 identified whether responders had project experience and therefore were eligible to answer this series of questions).

Table 19 Questionnaire Project and Risk Management

Question summary	% Agree	% Disagree
Risk assessment is well understood	36.7	40
Risk assessment tools and techniques are effectively applied	36.7	33.3
There are wide variations in the quality of risk assessments	86.7	3.3
ALARP is properly applied	43.3	30
Financial screening criteria does not reflect risks	53.3	6.7
No action is taken if risks sit in the ALARP region	36.7	36.7
There is benchmarking between companies to achieve good/best practice	31	44.8
There is benchmarking in the global organisation to achieve good/best practice	31	44.8
Managing risks in design is well understood	93.3	6.7
There are no conflicts in risk management in design with other objectives	14.3	78.6
Design provides the greatest opportunity to achieve cost-effective safety solutions for the lifetime of a development	85.7	7.1
There are adequate resources during design to achieve ALARP	42.9	28.6
During design project teams have accountability for the transfer of risks	29.6	44.4
There are KPIs for project teams in design to ensure ALARP for the development	17.9	57.1
In design project teams have suitable operational expertise	40.7	44.4
Project assurance prevent intolerable and non-ALARP risks being transferred	34.6	34.6
Projects, in design, are driven by cost and schedule. Safety is secondary	42.9	32.1
When design projects are fast tracked, safety is compromised	28.6	50
Risks transferred to subsequent phases are not always transparent	35.7	35.7

There is considerable uncertainty about the effectiveness of risk assessment and whether ALARP is being achieved. This may also be reflected in the risk differences between Europe, North America and the US identified in Figure 27. Similarly, it is inconclusive whether benchmarking is helping identify good/best practices in the industry. There is strong agreement that safety design is well understood and this phase provides the greatest opportunity for cost-effective solutions for the entire lifetime of a development (in agreement with s2.5 and s2.8). There is strong agreement that the current financial screening criteria used in projects does not reflect risks and

can compromise the ability of projects to achieve both tolerable and ALARP conditions (s2.3 and s2.5).

7.10.3 Measuring Performance

There were 9 questions in this category.

Table 20 Questionnaire Measuring Performance

Question summary	% Agree	% Disagree
The industry is too focused on injurious KPIs	60	16.7
Safety performance measurement is reliable	33.3	40
Safety measurement provides decision-makers with suitable information	33.3	16.7
Non-formal incident reporting systems, e.g. STOP, are given adequate attention	50	20
The organisation is aware that minor hydrocarbon releases can lead to major accidents	62.1	10.3
Employees are discouraged from reporting incidents	6.7	73.3
There is sufficient understanding of incident reporting requirements	24.1	31
Annually HSE address past deficiencies to provide a sound basis to achieve improvements	40	33.3
Resources to implement HSE plans are adequate	13.3	36.7

There is strong agreement that the industry is too focused on injurious KPIs (at the expense of non-injurious and process KPIs), and this is in agreement with s2.7). Also, there is strong agreement that organisations are aware of the potential danger arising from minor events (including hydrocarbon releases) which is in agreement with accident causation theory (accident triangles) in s2.7) and that reporting is encouraged. However, there is uncertainty about the general reliability and ability of these systems to improve safety performance.

7.10.4 Resilient Engineering (RE)

There were 22 questions in this category.

Table 21 Questionnaire Resilient Engineering

Question summary	% Agree	% Disagree
The concept of RE is well understood	4.5	18.2
Incidents are prevented by the flexibility of people	52.9	11.8
People are given adequate time to make safety decisions	11.8	70.6
People have time to review tasks (checks and balances)	47.7	26.5
Company emphasis of cost and schedule targets compromises safety performance	52.9	23.5
People have empowerment to stop unsafe acts	54.4	6.1
People and senior management know what is actually happening	17.6	55.9
Incident investigation is adequate to identify root causes	51.5	21.1
Safety defences erode under pressure	78.8	3
Past safety performance is taken as an indicator of future performance especially if it has been good	67.6	11.8
There is a fragmented approach to problem-solving that clouds the 'big picture'	70.6	17.6
Risk assessments are never updated to reflect change	82.4	2.9
Communications are poor	72.7	3
The organisation can respond rapidly and effectively to change	26.5	29.4
Lessons learnt are robustly captured to prevent recurrence	18.2	51.5
Auditing is adequate	26.5	17.6
KPIs prevent drifting into unstable conditions	34.4	25
There are adequate competent people to deliver asset integrity	34.4	25
There is a top-level commitment to deliver safety goals	58.8	14.7
The organisation is proactive to achieving safety goals	15.6	46.9
There is a 'Just culture'	55.9	14.7
There is a 'Learning culture'	38.2	17.6

The concept of RE does not appear to be well understood by the specialists who should have expertise in this area. Therefore the ability of responders to answer questions in this category might relate to the similarity of RE with traditional OH&S-MSs. On the positive side, there is strong agreement that incidents are prevented by the actions of people, rather than compliance with procedures, and they have the empowerment to stop unsafe acts. On the negative side, there is strong agreement that safety defences erode under pressure, risk assessments are not updated following change, and communications are poor. Issues about the time allowed to take decisions appear to be contradictory. There is uncertainty in the remaining features that are applicable to RE (reference s3.4).

7.10.5 High Reliability Organisations (HROs)

There were 9 questions in this category.

Table 22 Questionnaire High Reliability Organisations

Question summary	% Agree	% Disagree
The concept of HROs is well understood	14.7	20.6
The organisation is wary of success	12.5	40.6
Minor incidents are regarded as significant warning signals	62.5	12.5
There is an oversimplification of information	25	37.5
Near-miss reporting is adequate	53.1	3.1
There is an overload of incident information	21.9	40.6
There are sufficient competent people to accommodate change	22.6	35.5
Job rotation creates greater flexibility	38.7	19.4
There is a 'silo' culture	21.9	46.9

As with RE the concept of HROs does not appear to be well understood by the specialists who should have expertise in this area. Similarly, the ability of responders to answer questions in this category might relate to the similarity of HROs, and therefore RE, with traditional OH&S-MSs. Again considerable uncertainty exists about the application of HRO principles but the strongest area of agreement is that near-miss reporting is adequate (reference s3.5).

7.10.6 Inherent Safety

There were 22 questions in this category.

Table 23 Questionnaire Inherent Safety

Question summary	% Agree	% Disagree
The concept of inherent safety is well understood	60	13.4
The risk control hierarchy is applied	46.4	17.9
Designs are not always inherently safe	35.7	32.1
Procedures are often incomplete	46.4	32.1
Procedures often do not contain adequate detail	46.4	28.6
Procedures are often not concise	46.4	35.7
Procedures are often inconsistently formatted	39.3	28.6
Hydrocarbon systems are designed to minimise maintenance	7.4	55.6
Hydrocarbon systems are designed to minimise intervention	14.3	39.3
Hydrocarbon systems are designed to minimise joints	17.9	46.4
Process safety KPIs ensure integrity	25	35.7

Question summary	% Agree	% Disagree
Facilities are designed to be unmanned	21.4	50
Designs favour passive rather than active protection	50	14.3
Using inherent safety is cost-effective	33.3	25.9
Safety studies use inherent safety in decision-making	32.1	32.1
Senior management only sanction designs that are inherently safe	28.6	32.1
Lifecycle costs are considered in design to maximise inherent safety	17.9	46.4
Concept selection uses inherent safer design principles	33.3	29.6
Inherent safety in design will be compromised due to CAPEX	61.5	23.1
Inherent safety in design will be compromised due to lack of competent practitioners	50	30.8
RAM is identified as a KPI in design	22.2	29.6
Past incidents are addressed in the design phase	22.2	29.6

Unlike RE and HROs, the concept of inherent safety appears to be reasonably well understood. This may be because the concept has tangible and practical applications and is significantly different from RE and HRO theory. There is reasonable agreement that hydrocarbon systems follow the inherent safety hierarchy to reduce risk and that hydrocarbon systems are designed accordingly. However, the remaining responses were fairly balanced to present a level of uncertainty in the application of inherent safety in other areas (reference s3.2)

7.10.7 Normal Accident Theory

There was 1 question in this category.

Table 24 Questionnaire Normal Accident Theory

Question summary	% Agree	% Disagree
Risks tolerated are often acceptable	50	32.1

Risks that are taken may or may not be challenged. This is consistent with the findings in 7.10.1 where the quality of risk assessment was identified as variable (reference s3.3).

8. INTERVIEWS

8.1 Introduction

The purpose of the semi-structured interviews was to obtain specific qualitative information from a sample of the respondents in relation to information relevant to this research, (i.e. to probe for what is not known, and gain a range of insights on specific issues). The use of semi-structured interviews also allowed open discussion of the main research objectives to give interviewees the chance to expand on a particular topic. While there were other options available, such as structured and unstructured techniques, this approach provided an appropriate balance, to remain relatively focused without being too prescriptive. The interviews were either recorded electronically or hand written and the narrative that summarises the analysis from the interviews, extracted into subject areas, is provided below with subsequent examples that were quoted in the interviews.

8.2 OH&S-MS

The ineffectiveness of OH&S-MSs is comprised of factors such as inconsistent implementation of standards, lack of competencies, and a failure to cascade or communicate the safety culture of an organisation. While it is seen as positive to give managers more accountability for safety performance, this may actually have a negative impact if their ability to improve performance is limited, and they manipulate performance to give the impression of a better performance than the reality. If audits are undertaken, for example to meet targets, but the lessons learnt are not robustly captured, then the process is de-valued. Similarly, an OH&S-MS needs to deliver the means for improvement, and if new theories and concepts are excluded, opportunities to achieve safety goals are missed. Examples from the interviews are given below.

“The OpCo corporate OH&S-MS was not applied globally, so different standards were being applied, resulting in different risk levels for essentially similar activities within their operation”.

"There is a lack of young people being trained in the industry. When many of the older and experienced population retire, there is likely to be a huge loss of corporate memory".

"From a safety advisor's perspective, coaching people seems to yield good results".

"Middle management are a barrier/filter between senior management wishes and the workforce, so the safety message may not get through, or is obstructed, when the workforce try to implement senior management safety expectations".

"On a positive note, more line managers are being held more accountable for HSE performance".

"Still a large variation in the safety approach between oil and gas companies, also within an organisation, and even between departments".

"Many concepts such as resilient engineering, inherent safety and high reliability organisations, not fully understood".

"There is often a breakdown in communications and coordination between disciplines and departments that may contribute to errors and failures. Especially as Ops don't talk to projects who don't talk to maintenance who don't talk to Ops.....etc.!".

"There are sufficient detailed audits on the organisation to ensure that there is adequate compliance with safety policies, procedures and practices, and although we have the information, I don't think we share and compare, therefore we don't learn".

"I believe that most senior management is committed to achieving improvements in safety performance".

"There is effective workforce involvement in producing safety improvements, e.g. through safety committees, but you will never please everyone!".

The regulator can help guide, or through enforcement, demand improvement in, the OH&S-MS. The outcome from interviews relating to the regulator appears in this section. The general consensus amongst interviewees was that the North Sea regulator (UK HSE) is probably the most competent and active compared to others, but they suffer from under-resourcing and lack of experience. UK HSE finds recruitment of suitably-qualified and experienced personnel difficult as the salaries are generally lower than comparable positions in the private sector. Other, overseas global regulatory regimes are generally much slacker than the UK HSE, so it is easier to avoid implementing measures overseas to prevent /control/mitigate risks.

The ability of an organisation to achieve its safety goals is largely influenced by the resources it allocates to managing its risks. However, resource allocation is detailed in OH&S-MSs. In the interviews there was general consensus that cost management dominates decision-making. Although there are signs of improvement in safety culture, this may be a product of the recent (2010 – 2012) level of oil and gas prices and therefore higher revenues. However, proportionately, the amount of resource allocated to maintaining or improving safety performance is comparably the same as before.

“Cost drivers dominate decision-making, especially in this OpCo, as it used to be a contractor but it is now also an oil and gas operator, i.e. Duty Holder”.

“Four key pillars of projects: cost, schedule, reputation, and safety. The weighting given to each of these and the overall balance is driven by managers. But there is a large variation in the attitude of different managers to safety, and hence large variability in outcome”.

“Safety culture improving, but safety performance is still driven by cost and schedule”.

“Some managers still believe safety is the responsibility of the safety department, rather than the line”.

“Management spent money on HSE, but as a proportion of overall expenditure, it’s still relatively low”.

“Safety has a higher profile, compared to the past, but it is often just rhetoric, as enforcement and implementation of expectations meet various obstacles, e.g. cost, schedule, people”.

“Key concerns are:

- Too few good men on the ground.*
- There is a need to bring life to projects (practice rather than preaching) rather than just aim for ticks in the boxes.*
- Root cause - lots of politics in the organisation resulting in a dilution of genuine safety expertise, not enough senior competent safety people and people with practicable experience in key functions, e.g. production and well engineering”.*

“High cost-cutting in the production function, especially as unit costs increase (operating costs increasing while production rates declining) but this is not as relevant to well engineering, as high costs of drilling can absorb more easily higher safety expenditure. Also, well engineering is less prone to cost-cutting in the same way as production. But the proportion of safety costs compared to overall drilling expenditure still relatively small”.

“Lots of pressure to complete the work load on fewer people, for all disciplines, especially in exploration, due to high costs, tight schedules, and the need to get fast results”.

“The company emphasis on factors such as cost, schedule, production, etc. has had, and continues to have, a detrimental impact on safety performance but it’s about balance. HSE must be in there, and is, in most cases”.

“Safety defences (e.g. bow-ties) start to erode when under pressure, e.g. controls may be compromised due to cost, schedule, production pressures, which can be the case but I often think it’s an excuse as to why things go wrong”.

“We are pretty good at providing the resources we need to achieve safety performance targets (normally injurious-based targets)”.

It is evident, from the interview statements below, that while companies recognise the importance of a safety department (or personnel), there is concern about the ability to deliver professional safety support in conjunction with uncertain organisational expectations. In the worst case, this combination can be counter-productive and fail to improve safety performance.

“Although OpCo is now a major oil and gas company, until about 9 months ago (when interviewee joined) they had no Technical Safety Engineering expertise – a huge gap in the organisation. Much of the technical safety requirement is outsourced. Senior management does not understand the role of safety engineering and technical safety”.

“Quality of HSE/Safety Professional crucial in educating all employees, including senior management. OpCo has had a number of poor safety advisors”.

“No real ‘apprenticeship’ for safety people. While many are academically well qualified, their lack of practical experience limits their ability to influence safety decision-making, due to their inability to grasp basics”.

8.3 Risk and Project Management

Project Management

While project risks may be understood this does not mean they are managed to provide a lifecycle ALARP design. There may be various reasons for this deficiency but conflicts with other project

objects, e.g. cost and schedule, unnecessary transfer of risk to subsequent project phases, and lack of suitable competencies, may all contribute to poor [safety] designs. Examples from the interviews are given below.

- *"I think the requirements for managing safety risks during the design stages of a project are well understood".*
- *"There are always conflicts between the management of risks in design, and other project aims and objectives".*
- *"During the design phase sufficient resources are rarely provided to ensure that risks are adequately identified and mitigated to demonstrate an ALARP case (always on the back foot)".*
- *"We often see issues arise after the design phase because they haven't been understood and managed early enough to prevent the transfer of unnecessary risks to subsequent lifecycle phases".*
- *"Project Teams in general have insufficient operational experience to ensure that they can proactively minimise risks during the operational phase".*

Risk Management

Interviewees suggest, as demonstrated below, that the combination of poor quality procedures in an environment where risks are not fully understood is a recipe for failure to achieve safety objectives. The fact that the risk process is fragmented, and results are variable or out-of-date, is a recipe for poor safety performance. In the case of major accidents, continued focus on occupational safety distracts from the importance of process safety. A statement that an organisation remains vulnerable to blowouts is consistent with the SINTEFF results identified in the deductive research.

- *“Operations will always take the easiest route – procedures are often ignored or bypassed. Also, compliance with procedures not checked or audited”.*
- *“Good practice is being used in various OpCos, e.g. face fit PPE but often through informal networking”.*
- *“OpCo still focuses on occupational safety rather than process safety”.*
- *“People recognise the difference between occupational and process safety but there is a lack of attention given to process safety at the corporate level”.*
- *“Mentoring exists in the organisation but focus remains on occupational safety rather than process safety. Generally organisation waits for events like Deepwater Horizon before proactive interest is shown. Still lots of reliance on people ‘intuitively’ doing the right thing rather than taking a more scientific approach”.*
- *“Big problem with pipeline corrosion from saddles used on pipework supports. However, these are used extensively throughout the process and seem to be ignored as it’s in the ‘too difficult’ box and is likely to incur significant/major costs to rectify. No one wants to deal with issue”.*
- *“Verification big issue as some valves not working and/or leaking”.*
- *“Often risks are not fully understood and the quality of toolbox talks is poor”.*
- *“Well engineering still vulnerable to blowouts, although lots of positive noises about process safety. While well design is highly influenced by geology, it is not subject to a more holistic analysis and therefore tends to ring-fence individual wells as far as safety is concerned. For example, the choice of drilling technique could be wider to include underbalanced techniques that reduce safety-related risks but might increase drilling risks”.*

- *“Huge thrust on road safety (several road traffic fatalities) and Life Saving Rules (LSR) but no equivalent LSR for inherent safety, etc. The focus on road safety diverts attention away from process safety. Culture in Arabic nations seems less interested in safety culture so more difficult in these regimes”.*
- *“Continue using HAZOPs and FMEAs, etc. but normally these are used generically. However, more use of bowties, although many techniques are avoided at the corporate level because they don’t understand them or appreciate their value”.*
- *“Within the global or local organisation there is a fragmented approach to problem-solving that often clouds the big picture, i.e. there is not a shared risk picture when dealing with common hazards because we just make things too complicated! Having said that, the ‘eliminate, simplify, standardise, automate’ (ESSA) approach to things like the control framework in OpCo is starting to get rid of the crap we have out there, and allow for standardisation”.*
- *“Once risk assessments are carried out, they are not always revised to reflect changing circumstances as change management in general is not well carried out”.*
- *“The concept of Risk Assessment is well understood only by the HSE department. I don’t think other people really understand how to do this”.*
- *“There are wide variations in the quality of risk assessments within the organisation”.*
- *“There are sufficient opportunities for benchmarking or cooperation between oil and gas companies to implement good, if not best, practice but not extensively used”.*

8.4 Measuring Performance

Interviewees state that the industry mainly focuses on injurious incidents which are likely to have a greater impact on organisational behaviour than process-related incidents. While some improvements in reporting have taken place the data collected is often not used effectively in

incident prevention. Personnel may not fully understand the value of incident reporting and this may be reflected in the lack of data, in some cases. Annual HSE Plans, designed to identify safety improvement measures, are seen to be useful but are often rushed. This may produce reactive firefighting measures rather than well thought-out plans.

- *“All safety KPIs are injurious-based. Only recently did OpCo include first aid cases in their reporting requirements”.*
- *“Minor Lost Time Injury is still likely to have a greater impact in the OpCo than a minor gas release”.*
- *“Spills to sea are regular but no action is taken”.*
- *“Still emphasis on injurious KPIs rather than well kicks”.*
- *“Improvements have been made in well engineering to report near-misses, especially in process safety terms but often people do not see the value”.*
- *“There is a perception within the organisation that when past safety performance has been good, this is taken as a reason for future confidence about the adequacy of current risk control practices. Consequently we still focus on the 'reds' and don't challenge the 'greens' enough”.*
- *“There is sufficient emphasis on process safety KPIs to achieve continuous and sustainable improvements in asset integrity but I think we could still improve on what we measure and how, but it has to be smart and meaningful”.*
- *“The current approach to safety performance measurement should provide an immediate and reliable indication of the level of performance and although we have the data, I don't think we use it well enough”.*
- *“Informal reporting schemes such as safety suggestion, STOP, etc. should have adequate attention by the organisation in order to make a significant contribution in developing a*

proactive safety strategy but we don't use the data these schemes give us to identify weak areas".

- *"The organisation is sufficiently aware that minor hydrocarbon releases may be an underlying symptom of a larger problem that has the potential to lead to major accidents. But again we have to act on it. Measuring weeps and seeps is ok, but we fail to look at the wider picture and then identify trends, root cause, etc".*
- *"Employees are not discouraged from reporting incidents or near-misses for fear of reprisal".*
- *"There is a significant under reporting of incidents and near-misses as people often fail to recognise/identify what constitutes a near-miss".*
- *"Annual HSE plans have clear and transparent link to previous year's performance to remedy past failures, prevent repetition, and provide a sound basis to achieve future sustainable improvements in safety".*
- *"The resources provided to effectively implement the annual HSE safety plan are always adequate to achieve success. However, it's all about timing as it's always a rush as we have to wait for the 'top' to give us their steer".*

In the interviews there was one example, below, where there exists potential for a future major accident. This was identified in the following extract. It illustrates that the industry is still reactive, i.e. it waits for a disaster to happen before it considers its vulnerability.

- *"Following the Deepwater Horizon Disaster, assessment was carried out for the potential for a similar disaster in OpCo's global offshore operations. It was concluded that the potential for a major accident was higher than desirable".*

8.5 Resilient Engineering

Interviewees suggest that provision is made to allow people to work safely but it is often the people themselves that choose to rush decisions. This may be a cultural legacy, when the industry had to get the job done 'at any cost'. A feature of resilient engineering is to ensure stability by responding to change before adverse outcomes, but large organisations may be too bureaucratic to achieve this response, or indeed recognise that change is taking place. Many of the issues raised by interviewees are that systems are in place but not effectively applied. These are illustrated by the statements on HROs and Inherent Safety, below.

- *“Personnel should always have sufficient time to reflect on decisions to ensure avoidance of any unintended consequences. However, people don’t think they have the time and more often than not, create their own ‘workload’, believing it’s others doing it”.*
- *“The workforce is normally given sufficient time to provide adequate levels of checks and balances to proceed with their tasks safely but whether they choose to use it is another matter”.*
- *“People within the organisation have sufficient understanding of what is actually being practised and this is consistent with what senior management believe is happening, although managers often hear or see what they want to see and miss the reality”.*
- *“The organisation can respond flexibly and rapidly to changing demands, e.g. Asset integrity issues, although we are getting better at this, but the OpCo is too big (still) and decisions take too long to be made”.*
- *“Lessons learnt are adequately publicised. However, we don’t learn from them because we don’t reach root cause and hence we get a repeat”.*

- *“The organisation has sufficient proactive key performance indicators (KPIs) to help identify whether it is drifting from a stable into a less stable state where risks may be increasing, but we don’t use them effectively enough....”.*
- *“There are always sufficient competent and experienced people with adequate resources, e.g. time and money, in place to consistently deliver asset integrity but I doubt whether they are being used effectively”.*
- *“There is a 'Just Culture' in the organisation that encourages reporting of incidents but it does not accept negligent behaviours and the Life Saving Rules (LSR) has forced this, but I still think we need to be tougher and more consistent”.*

8.6 High Reliability Organisations

Statements given by interviewees indicate, as for OH&S-MSs, that the principles of accident causation and prevention are understood but a process for adequately capturing lessons learnt is lacking, and particularly for large organisations there is a failure to cascade information throughout the organisations.

“Even minor incidents are treated as evidence of a more serious, underlying, problem and these are considered as an early warning signal to take decisive action but we just don’t learn from incidents”.

“Not sure whether there is a 'silo' culture that inhibits openness and exchange of lessons learnt, practices and technologies”.

8.7 Inherent Safety

Procedures are considered lower order controls since they are often linked to numerous incidents and frequently cited as one of the causes of major accidents. The main causes of incidents was said to be too much reliance placed on procedures to control risk, a failure to follow safe working

procedures, or the use of inadequate procedures. Consequently, procedures may not be the best way of controlling hazards, particularly as the sole defence against human error, and this is supported by interviewees:

- *“Procedures are often incomplete or inaccurate, and this could be improved and simplified”.*
- *“Procedures often do not have sufficient detail e.g. that considers lessons learnt, the experience of users and their specific responsibilities. I don’t think we update our procedures robustly enough”.*

8.8 Summary

The interviews further support the results and discussions presented in the case studies, questionnaire and data analysis. This is illustrated by the following examples:

- The effectiveness of OH&S-MSs is compromised by factors such as inconsistent implementation of standards, lack of competencies, and a failure to cascade or communicate the safety culture of an organisation;
- While project risks may be understood that does not mean they are managed to provide a lifecycle ALARP design;
- The industry mainly focuses on injurious incidents which are likely to have a greater impact on organisational behavior than process-related incidents;
- Safety systems are in place but not effectively applied;
- The industry often lacks a robust process for adequately capturing lessons learnt and/or, particularly for large organisations, a system to cascade information throughout organisations; and
- Procedures may not be the best way of controlling hazards, particularly as the sole defence against human error.

9. CONCLUSIONS

In conclusion, each of the paragraphs discussed represents a specific issue in relation to the research aims and objectives. They are not mutually exclusive, and collectively provide a broad set of conclusions. Since they generally relate to OH&S-MSs there are applicable globally.

9.1 OH&S-MS

The various publically-available OH&S-MSs provide a framework to achieve safety goals but lack detail regarding resource allocation. Resource allocation, particularly in terms of cost, is seen to be a key driver underpinning safety performance which in turn is partly derived from an organisation's safety culture. However, it would be difficult to prescribe the level of resource allocation on an industry basis as variables such as hazard type(s), risk tolerability and risk level, differ considerably, both within large organisations, and across the spectrum of companies in the oil and gas business (re: s1.2, s2.3, s2.4, s2.5, s2.6, s2.8, s7.8, s8.2). Consequently, it may be beneficial to create more industry-wide recognised safety-related codes or standards that require mandatory implementation. This avoids the difficulties of achieving global statutory consistency, it allows ownership by the industry, and ensures a degree of continuity that provides a commercial 'level playing field'.

OH&S-MSs lack emphasis to ensure safety by design, i.e. inherent safety, during the early phases of a project, which is considered to be the most cost-effective approach when considering risk over the lifecycle of a development (re: s2.2, 5.9, 7.3, 7.10). This has resulted in inappropriate reliance on lower order controls, in the operational phase, e.g. procedures, to manage both occupational and major accident hazards (re: 8.7). This is due to a number of factors, but revolves around the traditional method of project management that tends to 'ring-fence' the financial and technical design elements at the start of a project's development to achieve the primary project viability and associated KPIs of cost and schedule (re: s2.5, S7.3). However, this approach is not likely to be cost-effective, when considered over the lifecycle of a development, since reducing

design costs associated with safety management is likely to disproportionately increase costs in subsequent project phases in order to combat the effects of lower order controls (re: s2.2, s2.5, s7.10).

It is evident in disaster investigation reports that effective implementation of OH&S-MSs has failed. This implies that effective implementation would have prevented the disaster, but given the continued occurrence of major accidents in the industry, it would suggest that this is not a random, unforeseeable problem, but represents a more fundamental failure to apply basic, well-established, tried and tested, safety management controls. Therefore, while OH&S-MSs may need revision to accommodate new safety management theories and concepts, there is no guarantee that these will be applied by some parts of the industry (re: s5.8).

Understandably, the industry has to manage its costs to achieve margins that allow it to operate, compete, invest, and satisfy stakeholders. Equally the industry has inherent major accident hazards that it creates and therefore has to manage safely (re: s2.3). When the balance swings more towards reducing costs than protecting people, major accidents can ultimately occur as safety systems are compromised. Unfortunately the swing towards cost reduction, and its eventual effects, such as a major accident, may lay dormant for some time, during which further cost reductions may have occurred or the industry has assumed that the reductions have had no adverse impact on safety performance. This has been demonstrated through major accident investigation reports (re: s2.5, s3.2, s7.3, s7.5, s7.7).

There are examples demonstrating that the regulator has been ineffective in its role of protecting people at work. This may be due to a number of factors, such as conflicting interests, and/or inadequate resourcing. Moreover, in the UK, given the move from a relatively prescriptive regulatory regime to a goal-setting regime, it is difficult to determine how this change of accountability or emphasis has, or will, improve regulatory oversight, and industry safety

performance. This may be especially important if there is a safety culture that 'normalises' risk to levels that may not be tolerable or ALARP (re: s3.3, s5.6).

In recent years the industry has focused on human behaviour as a means of trying to improve its safety performance. While themes such as 'just culture' and human factors are likely to help towards improvements in safety, although they might be regarded as 'tail-pipe' solutions, any overemphasis of their contribution is equally as likely to distract from implementation and development of the more important concepts such as inherent safety (re: s3.5, s8.5).

The safety department is instrumental in supporting an organisation meet its safety goals, and implementing the OH&S-MS. However, disparities between organisational expectations of its safety personnel, and the ability of those personnel to provide professional services is seen as a potential issue (re: s3.7).

9.2 Project and Risk Management

Developments are typically divided into distinct phases, each of which is normally subject to different projects characteristics relating to people, environment, risk, economics, and so on (re: s.2.5). Early phase project teams are usually transient and consist of contractor personnel, since in lifecycle terms this is a relatively short period and therefore has little longer-term viability (re: s7.3). This allows organisations to shed employees on completion of this phase, and the team may thus lack the authority or motivation to seek inherently safer designs, especially if this could compromise conventional project KPIs of cost and schedule. Cost and schedule are driven by the need to minimise design and construction costs, and maximise revenue generation, by achieving production as soon as possible after a final investment decision for a development is obtained. This combination could result in designs that might satisfy specifications but still fail to achieve inherent safety (re: s3.2, s7.7). This results in the unnecessary transfer of risks to subsequent phases that will either require a relatively higher expenditure to rectify or place reliance on lower

order controls (re: s3.2, s7.3). Furthermore, this situation may not be identified given the variability, and flexibility, of risk management tools, techniques and assessment of the tolerability of risk.

9.3 Measuring performance

The industry primarily relies on reactive and injurious based data to assess its safety performance (re: s2.7, s7.4, s8.4). However, the way it collects, collates, analyses and disseminates this information is flawed and only provides a very limited picture of actual safety performance. The data tends to be reactive and include only injurious events (re: s2.7, s5.6, s6.6, s7.4, s8.4). Only recently have process safety-related events been considered important, although these are the events that are more likely to lead to a major accident. In this context the warning signals required by the OH&S-MS, and theories such as resilient engineering and high reliability organisations, are missing. The data may be misleading, for example it could give the impression of a better safety performance than actually exists or could cause organisations to target the wrong accident prevention strategies. Compilation and access to major accident industry-wide data sources appears to be fragmented and limited despite this being a valuable asset for decision-making. Even the UK HSE does not make its major accident database freely available to the public. The data itself is often confusing due to the ways databases are constructed, with variations in definitions (re: s2.5, Ch 6). While many of the immediate causes of incidents are relatively unique, many of the root causes have elements of commonality. The OH&S-MS links both occupational and safety incidents although they are often treated separately. Measuring performance, at the industry-wide level, is therefore unlikely to be cost-effective and provide the information needed to reflect actual safety performance and provide warning signals in sufficient time to allow proactive measures to be implemented before adverse outcomes occur.

9.4 Challenges to Traditional OH&S-MSs

Resilient engineering and high reliability organisations require systems to be sensitive to change in order that timely and appropriate adjustments are made before a failure occurs (re: s3.4, s3.5, s7.5, s7.6, s8.5, s8.6). This is particularly important when management demands that an organisation act faster, cheaper and better (re: s3.4). Resilient engineering suggests that OH&S-MS are too linear and this does not reflect organisational complexity, which requires a more systemic approach to safety management. While the theory has merit, its practical application has uncertainty although the concept does support the concerns associated with the traditional methods of measuring performance described above. High reliability organisations stress the importance of 'mindfulness', placing emphasis on individuals, as discussed in Human Factors. While this concept also recognises the value of safety departments in accurately measuring performance and feeding this information back as part of accident prevention strategies, both concepts appear to reinforce components that have previously been identified by the industry. However, what they propose is essentially more effective implementation of the relevant components of an OH&S-MS.

Inherent safety generally relates to design and hardware systems. It provides a hierarchy of measures that can eliminate, by removing the hazard or the people, or mitigating the potential risk (re: s3.2, s7.7). It is a 'first-order' control but is not applied extensively across the industry. This may be due to a number of contributing factors such as potentially higher initial costs compared to non-inherently safe designs, and/or a lack of understanding of inherent safety by the industry, and its practitioners, e.g. technical safety professionals. It may also be due to the methods used to allocate costs during project phases, as inherent safety may involve higher initial costs but it is believed that the overall lifecycle costs can be considerably lower compared to non-inherently safe designs. There is also a lack of KPIs that steer projects towards inherent safety,

and therefore there is no incentive to produce designs that might compromise traditional project KPIs of cost and schedule. However, inherent safety offers the industry an opportunity to produce cost-effective designs that can either eliminate, or substantially reduce, the future potential for disasters, and through mandatory application, ensure a commercially 'level playing field'. This also allows the industry to become more competitive against other forms of energy producer but would require a radical re-think of project development strategies, for implementation.

Normal Accident Theory (NAT) assumes that accidents are inevitable, i.e. it is just a matter of time, due to the complexity and tightly-coupling of plant designs that cannot identify, and therefore control, all the various failure permutations (re: s3.3, s7.8). The recommendations of NAT are essentially to improve the effectiveness of OH&S-MSs, and where this cannot be done, to achieve suitable levels of risk tolerability. The project should be abandoned if it offers society little value. However, this is not a new theory but, perhaps, a better description of existing ones.

9.5 Case Studies

The case studies, and inductive research, demonstrate that since Piper Alpha, the industry remains vulnerable to major accidents (re: s7.2, s8.3). While the immediate causes of the disasters may vary considerably, and therefore are unlikely to be repeated, many of the root causes show some commonality. The industry does not appear to have learnt lessons from past disasters, or if it has, the lessons have not been robustly captured on an industry-wide basis (re: s5.8). Given that many of the controlling systems, e.g. OH&S-MSs, are essentially unchanged since Piper Alpha, there is no reason to suggest that the industry is better placed to prevent future disasters, as the root causes of failure, (re: s5.3, s5.4, s5.5 and s5.6) are deeply embedded in these systems.

9.6 Database Analysis

The primary objective of an OH&S-MS is to achieve continuous and sustainable improvements in safety. Unfortunately this is not demonstrated by the data, which often shows wide variations in annual performance. There is no link between occupational safety and process safety data, and the data published shows little direct comparison with accident causation theory. The primary aim of an OH&S-MS is to obtain continuous and sustainable improvements in safety performance. However, in the main, these objectives are not supported by the data (re: Ch 6).

9.7 Questionnaire

The questionnaire was aimed at qualified and experienced safety practitioners, i.e. those people with the necessary competencies to help direct organisations achieve their safety goals. The results are very mixed which perhaps reflects the diversity and complexity of the subject matter, but also differences between the global industry approach, and possible variations in implementation, of OH&S-MSs and associated components, between individual oil and gas companies (re: s7.10). The results from the questionnaire did not reveal anything that significantly contradicted the other findings in this research nor did it add any significant new findings that might influence these conclusions.

9.8 Interviews

The purpose of the semi-structured interviews was to obtain specific qualitative information from a sample of the respondents in relation to information relevant to this research, (i.e. to probe for what is not known, and gain a range of insights on specific issues). The use of semi-structured interviews also allowed open discussion of the main research objectives to give interviewees the chance to expand on a particular topic (re: Ch 8). Similar to the results from the questionnaire, although interviewees were not influenced by the questionnaire, the results did not reveal

anything that significantly contradicted the other findings in this research nor did it add any significant new findings that might influence these conclusions.

10. RECOMMENDATIONS AND FUTURE RESEARCH

The oil and gas industry operates in a particularly dynamic and competitive environment, which is subject to constant, and often unpredictable, change. Therefore it is difficult to obtain the consistency and continuity required to achieve the goal of continuous and sustainable improvements in safety performance, given all the variables that can, and in some cases cannot, be influenced by oil and gas companies. Consequently, the industry has to look for solutions that are less affected by the vagaries of the internal and external influences impacting safe global oil and gas exploration and exploitation, while ensuring they are cost-effective, and add value.

10.1 Recommendations

- OH&S-MSs must be applied more effectively by developing global mandatory safety-related standards that provide a 'level playing field' within the oil and gas industry. This ensures, assuming compliance, that no organisation has a commercial or competitive advantage over another. It mitigates the vagaries of cost-dominated decision-making on the ability to achieve safety goals. It also allows the industry to consolidate good and best practice, and is consistent with a goal-setting regulatory regime that requires the industry to adequately manage the risks it creates. Given the global nature of many oil and gas organisations it also provides for greater consistency and continuity of safety practices used by the global workforce.
- OH&S-MSs need greater focus on how to address safety management during the lifecycle phases of a development, and in particular, to emphasise how the design phase can be exploited to provide the most cost-effective safety-related solutions in achieving safety goals over the life time of a development.
- There needs to be a more informed basis for safety performance decision-making. Consequently, the industry has to improve the way it reports, collates, conducts analyses, and disseminates safety-related performance data. This ensures that suitable and sufficient

warning signals alert the industry to general industry instabilities that need to be corrected before adverse outcomes. This should, as a minimum, also include the findings from major accident investigation reports. It will allow the industry to more accurately benchmark performance, but requires a more balanced view of reactive and proactive measures of safety performance, together with occupational and process safety data.

- In each project, the industry has to embrace and implement, more fully, the concept of inherent safety, to focus the industry on the hierarchical safety-related decision-making that contributes to achieving both tolerable and ALARP risks. This should be included as an industry-mandatory standard. The application of inherent safety should also be included as a primary project KPI which is sanctioned by senior management.
- Financing design projects should be based on total lifecycle costs rather than ring-fencing each project phase. This provides greater opportunity to increase capital costs at the design phase, when compared with like-for-like traditional design projects, to create more cost-effective safety solutions when viewed over the lifetime of a development.
- The quality and consistency of risk management has to be improved in the industry. Since many oil and gas companies have similar hazards, a universal set of risk assessments should be published to aid risk-based decision-making. Similar to the HAZID guidewords provided in ISO 17776, these risk assessments provide a generic approach that can be used by the industry to help benchmark good or best practice but are not intended to be a substitute for work or site specific risk assessments.

10.2 Future Research

The recommendations require further research to establish how they can be applied, and potentially improved, to increase their contribution in making cost-effective, continuous, and

sustainable safety improvements in the oil and gas industry. However, additional areas of research that could also contribute to improve safety performance are discussed below.

- The move from a prescriptive to goal-setting regime, and the associated role of the regulator, requires research to ascertain how this might improve safety.
- Research is needed on how design teams can be held more accountable for how safety is managed in subsequent project phases, especially when transferred risks are often not understood by the departments which are to manage them.
- Research is required into how new concepts such as resilient engineering, high reliability organisations, and normal accident theory are evaluated by recognised industry bodies (such as the British Standards Institute) to see whether they offer added value and ought to be incorporated into OH&S-MSs, or identify the justification for their exclusion.
- The role of the safety professional, and safety department, needs to be reviewed to ensure that the type and quality of the support available, and their ability to influence decision-making, is commensurate with the risks created by the organisation.

Appendix A Comparison of Key Characteristics of HROs from Three Separate Sources

Quality	Learning from HROs [307]	Characteristics [313]	Moving to High Reliability [360]
Preoccupation with failure	Organisations are wary of success since it breeds complacency. Small failures or errors may be evidence of a more serious problem and act as early warning signals. This triggers a response in HROs that might be ignored elsewhere (mindfulness). There is a culture where people are prepared to report incidents (including near misses/hits).	HROs are preoccupied with events they seldom see. They consider even the smallest error as a sign that something could be wrong with the system. Near-misses/hits are seen as failures and not evidence of success. They assume errors will occur and therefore have the potential to lead to incidents	HROs spend energy thinking about mindful anticipation and awareness and in mindful containment.
Reluctance to simplify	Over simplification of information means some vital data may be lost that could have been used to prevent incidents. Cost-cutting organisations see people as redundant and this is part of the concept of efficiency. In HROs there is a 'pool' or surplus of personnel (slack) that acts as a buffer to maintain continuity and consistency during periods of change	HROs try to understand the nature of the operation and its activities by extricating detail since oversimplification can result in misleading perceptions about the business. This way it is believed they will get early warning signals about potential failures. Consequently, fewer assumptions are made and decision-making is more valid. HROs carry out frequent job rotation and use employees with non-typical job experience. This produces greater depth and more challenges in decision-making, and therefore the organisation can better cope with the expected.	Mindful Awareness and Anticipation of the Unexpected Preoccupation with failure Reluctance to simplify Sensitivity to operations
Sensitivity to operations	Organisations attempt to continually understand what is happening (and why) in order to plan for the future. The 'silo' culture is discouraged and openness and awareness of the big picture is endorsed so that underlying symptoms are identified and lessons are learnt to prevent failure	This is to recognise, for example, the Swiss Cheese model and trying to locate where the holes are located. It tries to communicate the 'big picture' ensuring that this is cascaded, shared and kept up-to-date throughout the workforce. So by identifying the risk position and ensuring people are aware of organisational requirements, people can make the necessary adjustments that prevent errors or failures.	Tips to improve the above practices are: Restate your goals in the form of mistakes that must not occur Create/practice mindful moments
Commitment to resilience	The signature of an HRO is that they show a commitment to resilience so that when errors occur (acknowledging that errors will happen), then the organisation will not be disabled by them	This is seen as a combination of maintaining errors within boundaries such that there is no significant adverse outcome. The organisation can contain the unexpected and in this context, in particular, some improvisation is allowed to maintain the system within tolerable limits.	Mindful Containment of the Unexpected Commitment to resilience Deference to expertise
Deference to expertise	The decision to launch the Challenger space shuttle was made against the advice of the experts. Similarly, managers of pipelines feeding into Piper Alpha failed to shut them down in a timely way to minimise escalation. Decision-making must come, at some point, from those best placed to make the right decisions, e.g. empowerment.	This allows the organisation to adapt to change by allowing people to make decisions if they have the appropriate expertise and experience, regardless of rank. This is effectively a hybrid of hierarchy and specialisation.	Tips to improve the above practices are: Begin to contain the event by doing what experience tells you to do, but remain in doubt that you're doing the right thing Enlarge competencies and response repertoires (resilience takes deep knowledge) Accelerate feedback (slow feedback will lead to failures)

Appendix B Industrial Major Accidents

Legend

LR Land Rig

JU Jack Up

DS Drill Ship

P Platform

SS Semi Submersible

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1947 April 16	Texas City	578		Ammonium nitrate	Fire and explosion	Detonation	3500	
1948	Ludwigshafen, Germany	207	Chemical tank wagon		Explosion			
1948 Mar 08	Alberta, Canada	0	LR		Blowout	Major release, fire		
1956 Aug 10	GOM	4	JU		Sinking	Under construction		
1956 Dec	Arabian Gulf	20	JU		Sinking	Collapsed during tow.		
1957	GOM	0	JU		Sinking	Sank after hurricane		
1957 Mar 31	GOM	1	JU		Sinking	Tilt, capsized H. Audrey		
1959	GOM	0	JU		Sinking	Punch through, capsized before move		
1963 May	German CS	0	JU		Blowout	Crater		
1964	Niigata Japan	2	Refinery	HCs	F, EX			87.3
1964 Jun 30	GOM	22	DS		Blowout	Catamaran type, explosion and fire		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1965	GOM	0	JU		Sinking	Punch thru, overturn H. Betsy		
1965 Sep 09	GOM	0	JU		Sinking	PT, capsized moving, H. Betsy		
1965 Sep 09	Off Ravenna, Italy	0	JU		Blowout	Destroyed by fire		
1965 Dec 27	UK CS	13	JU		Sinking	BP, jack collapse, brittle fracture		
1966	Raunheim, FRG	3	Ethylene	Methane, ethylene	VCE		83	26.6
1966 Feb 09	West Africa	0	JU		Sinking	Fast leg penet, capsized, sank		
1968 Mar 07	UK CS	0	SS		Sinking	Broke up in storm		
1968 Mar 13	GOM	0	JU		Sinking	Sank in bad weather on tow		
1968 Apr 28	GOM	0	JU		Sinking	Overturned due to soil failure		
1968 Aug	-	7	JU		Blowout	Fire off La. Coral Drilling		
1969	Puerto La Cruz	0	Crude Unit	HCS	F, EX			15.6
1969	Canadian Arctic	0	LR		Blowout	Ice volcano		
1969 Jan 28	Dos Cuadras F, OCS, US	0	P		Blowout	Major release		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1969 Mar	GOM	0	JU		Sinking	Grounded in extreme weather		
1969 Nov	NS	0	JU		Sinking	Sank in bad weather on tow		
1969 Nov 22	Canary Islands	0	JU		Sinking	Sank in tow		
1970	Agha Jari, Iran	10	Compressor Station	Gas	EX		10	NS
1970 Feb 10	GOM	0	P		Fire	Burned for 2 months		
1970 Oct 25	Canadian Arctic	0	LR		Blowout	Ice volcano		
1970 Dec 01	GOM	4	P		Blowout	Platform lost		
1971	Georgia	29	Chemical		Fire and explosion	Flares ignited by a fire and detonation occurred.	50	
1972	Trieste, Italy	0	Terminal	Crude oil	F			29.7
1973 Aug 08	Venezuela	0	P		Blowout	Major release		
1974 Jan 01	UK CS	0	SS		Sinking	Leg broke, capsized		
1974 June 01	Flixborough UK	28	Chemical	Cyclohexane	Explosion		38	
1974 Oct 09	-	18	JU		-	Punch thru, leg failure		
1974 Nov	South America	0	JU		Sinking	Weather, flooding, sunk		
1975	Philadelphia, USA	2	Tank Farm	Crude oil	VCF, EX		2	26.5
1975	Norwegian CS	03-Jun	P		Fire	-		
1975 Mar	GOM	0	JU		Blowout	Sank off La.		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1975 Sep	Persian Gulf	0	JU		Sinking	Sank in tow. ArabAmOilCo		
1976	Los Angeles, USA	0	Terminal	Crude oil	EX			23.2
1976	Plaquemine, LA	0	Surge Tank	Oil	IE			23.2
1976	Caspian Sea	0	JU		Sinking	Capsized, sank, new rig		
1976 Jan	-	0	JU		Sinking	-		
1976 Feb	Off Dubai	0	JU		Sinking	Sank, hit by barge in storm		
1976 Mar 01	Norwegian CS	6	SS		Grounding	Storm		
1976 Apr 15	GOM	13	JU		Sinking	Capsized on tow in bad weather		
1976 June 10	Seveso Italy	0	Chemical	Dioxins	Release	3000 Pets and farm animals died. 70,000 slaughtered	193	
1977	Umm Said, Qatar	7	Gas Plant	LPG	F		13	139
1977 Jan 12	West Pacific	0	JU		Sinking	Sank in bad weather during tow		
1977 Apr 22	Norwegian CS	0	P		Blowout	Major release		
1977 Jun	West Africa	0	JU		Sinking	Sank in bad weather on tow		
1977 Sep	-	0	JU		Sinking	Sank in tow, salvaged, retired		
1978	Abqaiq, Saudi Arabia	0	Gas Plant	Methane, LPG	F, VCE			90.8

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1978	Texas City, TX	7	Storage Vessel	LPG	BLEVE		10	93
1978 Feb 01	Guernsey, UK	0	JU		Grounding	Broke loose from barge		
1978 March 16	Northwest coasts of France	0	Amoco Cadiz Oil tanker		Sunk	Spill 68,684,000 US Gallons of crude oil		
1979	Geelong, Australia	0	Crude Unit	Oil	F			17.4
1979 March 28	Dauphin County, Pennsylvania	0	Three Mile Island Nuclear Plant	Radioactive	Release	481 PBq (13 million curies) of radioactive gases were released		
1979 May 10	GOM	8	JU		Sinking	Fatigue, collapse		
1979 Jun 03	GOM	0	SS		Blowout	IXTOC 1 - Capped 1980 Mar 23		
1979 Nov 25	Bay of Bohai, China	72	JU		Sinking	Storm. Sank in tow.		
1980	Borger, TX	0	Alkylation Unit	Light HCs	VCE		41	48.5
1980	Brooks, Alberta	0	Compressor Station	Natural gas	EX			55.6
1980	GOM	0	JU		Sinking	Mudslide, total loss		
1980	South America	0	JU		Collapse	Legs damaged, seabed slide		
1980 Jan 01	Nigeria	0	SS		Blowout	Sedco 135c, fire, scuttled off Nigeria		
1980 Jan 17	Nigeria	0	P		Blowout	Major release		
1980 Feb	GOM	0	JU		Sinking	Weather, valve failure, flooding.		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1980 Feb 05	GOM	0	JU		Sinking	Sank in tow, salvaged, in service		
1980 Mar 09	GOM	0	P		Blowout	Killed after 1 day		
1980 Mar 27	Norwegian CS	123	SS		Sinking	Fatigue fracture caused capsized		
1980 Jun 15	-	70	JU		Blowout	Fire		
1980 Aug 09	GOM	0	JU		Sinking	Hurricane Allen, on location		
1980 Oct	Arctic	0	JU		Grounding	Grounded in bad weather		
1980 Oct 02	Persian Gulf	19	P		Blowout	Major release		
1980 Oct 02	Saudi Arabia	19	JU		Blowout	Hasbah Platform blowout		
1980 Oct 18	Gulf of Suez	73	JU		Blowout	Derrick collapse, renamed EDC Setty		
1980 Oct 22	Alaska, North Pacific	0	JU		Sinking	Sank in bad weather on tow		
1980 Nov 21	Louisiana	0	-		Sinking	Drilled into salt mine		
1980 Dec	Port Said	0	JU		Grounding	Grounded in bad weather		
1981	Shuaiba, Kuwait	1	Tank Farm	Oil	F		1	124
1981	West Pacific	0	JU		-	Slipped on location		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1981 Aug 27	South China Sea	0	DS		Blowout	Sank after blowout		
1982	Edmonton, Alberta	0	Compressor	Ethylene				24.6
1982	Kashima, Japan	0	Desulphurisation Unit	HCs	F			16.3
1982	Cabinda, Angola	0	JU		Sinking	Lost, shallow gas blowout		
1982 Feb 15	Hibernia, N. Atlantic	84	SS		Sinking	Storm, Mobil		
1982 Oct 17	Alberta, Canada	2	LR		Blowout	Amoco, major H2S release		
1983	Bontang, India	0	LNG	LNG	IE			57.5
1983	Milford Haven, UK	0	Storage Tank	Crude oil	F		20	17.3
1983	Basile, LA	0	Gas Plant	HCs	VCF			33.9
1983 Mar	Persian Gulf	20	P		Fire	Major release		
1983 May 15	SNS, NL	0	P		Blowout	Corrosion		
1983 Jul	GOM	0	JU		Blowout	Sank in blowout off Texas		
1983 Sep 01	Australia	0	JU		Sinking	Sank in bad weather. Salvg 12-83		
1983 Sep 09	Caspian Sea	5	JU		Sinking	Seabed failure, volcanic action		
1983 Oct 25	S. China Sea	81	DS		Sinking	Capsized in tropical storm Lex		
1983 Nov 05	Norwegian CS	5	SS		Explosion	Diving accident		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1983	-	0	P		Blowout	Abandon		
1984	Abbeystead, UK	16	Valve House	Methane	EX		28	NS
1984	Las Piedras, Venezuela	0	Hydro-desulphuriser	Oil	F			70.1
1984	Mexico City, Mexico	650	Terminal	LPG	VCF, BLEVE			22.5
1984	Romeoville, IL	15	Absorption column	Propane	VCE, BLEVE		22	143.5
1984	UK CS	0	SS		Grounding	Broke moorings		
1984	Norwegian CS	0	SS		Blowout	Shallow gas		
1984 December 03	Bhopal India	4000 - 20,000	Chemical	Methyl isocyanate	Release			
1984 Feb 22	Sable Island, N. Atlantic	0	SS		Blowout	Shell, Uniacke G-72		
1984 May 13	West Cameron, GOM	1	P		Explosion			
1984 Aug 16	Enchova Field, Brazil	37	P		Blowout	Fire, lifeboat fell to sea		
1985	Tioga, ND		Gas Processing	HCS	IE, VCE			11.3
1985	Javan coast	0	JU		Blowout	Fire		
1985 Jan	UK CS	2	SS		Explosion	Pump room		
1985 Jun	Indian Ocean	0	JU		Sinking	Sank in bad weather on tow		
1985 Oct 06	Haltenbanken, Norw. NS	1	SS		Blowout			
1985 Oct 28	GOM	1?	JU		Sinking	Sank in H. Juan		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1986 April 26	<u>Prypiat, Ukraine</u>	50	Chernobyl Nuclear Power Plant	Radioactive	Nuclear meltdown		4000+	
1986 Oct	Mexico	0	JU		Blowout	Sank after blowout		
1986 November 1	Sandoz, Schweizerhalle, Switzerland	0	Chemical	Toxic agrochemicals	Fire and Spill	Massive mortality of wildlife		
1986 Nov 20	Indian Ocean	0	JU		Sinking	Stbd leg PT, capsized, off Bombay		
1987	Port Herriot, France	2	Storage	Oil	F		8	NS
1987	Ras Tanura, Saudi Arabia	0	Gas Plant	Propane	VCE			67.2
1987	GOM	0	JU		Sinking	Soil failure while drilling		
1987 Oct 20	GOM	0	JU		-	2 bow legs PT		
1987 Nov 04	GOM	0	P		Blowout	Platform tilted		
1987 Dec 20	Cook Inlet, Alaska	0	P		Blowout	Fire. Unocal, Penrod rig also lost		
1988	Port Arthur, TX	0	Storage	Propane	F			17.4
1988	-	0	JU		Collision	Merchant ship		
1988	Norwegian CS	0	P		Collision	Sub collision - anchor chain		
1988 Feb 22	GOM	0	JU		-	PT, legs bent, total loss.		
1988 Apr 24	Enchova Field, Brazil	0	P		Blowout	Destroyed by fire		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1988 May 05	Norco, Louisiana,	7	Refinery	hydrocarbon gas	Explosion	Corroded pipe in a catalytic cracker	42	
1988 Jul 06	UK CS (Piper Alpha)	167	P		Fire	Explosion and loss after gas leak		
1988 June 28	Auburn, Indiana,	5	Metal-plating		Confined Space	Improper mixing of chemicals		
1988 Sep	SE Borneo	4	DS		Blowout	Explosion and sinking. Total Oil		
1988 Sep 22	UK CS	1	SS		Blowout	Fire		
1988 Dec 15	North Atlantic	0	JU		Sinking	Sank in bad weather during tow		
1989	Baton Rouge, LA	0	Refinery	Ethane, propane	VCE			44.7
1989	Indian Coast	3	JU		Blowout	Fire		
1989	Norwegian CS	0	P		Fire	-		
1989 Jan 08	GOM	0	JU		Blowout	Total loss		
1989 March 24	Prince William Sound's Bligh Reef		Exxon Valdez, an oil tanker	Crude Oil	Spill	10.8 million US gallons (40.9 million litres, or 250,000 barrels) of crude oil		
1989 Apr	GOM	0	JU		Sinking	Sank in bad weather on tow		
1989 Apr	Offshore S. Africa	0	SS		Sinking	Capsized during tow		
1989 Apr 18	NS	0(3?)	P		Explosion	Gas leak		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1989 Apr 28	Nigeria	5	JU		Blowout	Burned & sank		
1989 October 23	<u>Pasadena, Texas</u>	23	Chemical	Flammable gas		Due to maintenance operations on one of the plant's polyethylene reactors	314	
1989 Nov 03	Gulf of Thailand	91	DS		Sinking	Typhoon Gay		
1989 Nov 08	North Sea	0	JU		Sinking	Flooded in bad weather on tow		
1990	Nagothane, Bombay	31	Ethylene Plant	Ethane, propane	VCE			22.4
1990	Ras Tanura, Saudi Arabia	0	Refinery	HCs	F			23
1990 May 30	GOM	0	JU		Blowout	-		
1990 Aug 20	North Sea	0	JU		Sinking	Sank in bad weather during tow		
1991 Aug	NS	0	P		Explosion	Shell		
1991 May 01	Sterlington, Louisiana	8	Chemical	Nitro-paraffin	Explosion		120	
1991 Aug 23	Norwegian CS	0	P		Sinking	-		
1992 Aug 27	GOM	0	JU		Hurricane	Major damage, collapse		
1992 Sep 29	GOM	0	JU		Blowout	Major release, fire		
1993 Feb	Vietnam	0	SS		Blowout	Major release		
1993 Nov	Arabian Gulf	0	JU		Sinking	Flooded in bad weather on tow		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
1994 Dec 01	GOM	1	JU		Fire	Leg struck pipe. Damaged, repaired		
1995 Aug	Northern Angola	0	SS		Sinking	Sank on tow		
1996	Nigeria	18	P		Fire	Explosion		
1996 Jan	Suez	0	JU		Sinking	Sank in bad weather on tow		
1996 Jan 24	GOM	0	P		Blowout	Fire		
1996 Apr	GOM	0	JU		Sinking	Weather, structural failure, flooding		
1997	GOM	0	JU		Sinking	Breakthrough/slide into crater		
1997 Apr 01	GOM	0	P		Blowout	Fire		
1998 Jan	West Atlantic	0	JU		Sinking	Legs lost. Sank 97		
1998 Jun	GOM	0	JU		Sinking	Sank in bad weather on tow		
1998 Jul	-	2	SS		Explosion	-		
1998 Jul 17	GOM	0	P		Collapse	-		
1998 Dec 03	GOM	0	P		Sinking	Lift failure, dropped module		
1999 Sep 09	GOM	0	P		Blowout	Fire		
1999 Nov 02	Indonesia	5	SS		Sinking	Hit rock		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
2000 Apr 15	Persian Gulf	4	JU		Collapse	Jack failure while skidding derrick		
2000 May	BP Grangemouth	0						
2001 Mar 01	Eugene Isl Blk 273, GOM	0	JU		Blowout	Setting casing string, fire		
2001 May 09	GOM	0	JU		Blowout	-		
2001 Mar 15	Campos Basin, Brazil	11	P		Sinking	Explosion		
2001 Jun 19	Bicudo Field, Brazil	0	P		Blowout	Fire		
2001 Jul 13	GOM	0	JU		Blowout	-		
2001 September 21	Toulouse, France	29	Chemical		Explosion	Fertilizer factory	2500	
2002 Aug 09	Grand Isle 93, GOM	0	JU		Blowout	Fire		
2002 Sep 30	Saudi Arabia	0	JU		Blowout	Fire destroyed rig and platform		
2002 Oct 02	GOM	0	JU		Sinking	Lili - collapse and capsized		
2003 Sep 11	GOM	0	JU		Collapse	Jacking mechanism failure		
2004 Aug 10	Med Sea, Egypt	0	JU		Blowout	Fire destroyed rig and platform		
2004 Sep 15	GOM	0	JU		Hurricane	Major damage		
2004 Sep 15	GOM	0	P		Hurricane	Damaged		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
2004 Nov 28	Norwegian CS	0	P		Blowout	Seabed gas blowout		
2005 March 23	Texas City, Texas	15	Refinery	Hydrocarbons	Explosion		100	
2005 Jul 10	GOM	0	SS		Hurricane	List after Dennis.		
2005 Jul 27	Indian Ocean	22	P		Fire	Boat impact		
2005 Aug 29	GOM	0	JU		Hurricane	Katrina - derrick fell on rig		
2005 Aug 29	GOM	0	SS		Hurricane	Major damage		
2005 Aug 29	GOM	0	P		Hurricane	Major damage		
2005 Aug 31	GOM	0	JU		Hurricane	Major damage		
2005 Aug 31	GOM	0	JU		Hurricane	Katrina - Capsized		
2005 Sep 09	GOM	0	JU		Hurricane	Major damage in Rita		
2005 Sep 27	GOM	0	P		Hurricane	Major damage		
2005 Sep 28	GOM	0	JU		Hurricane	Major damage		
2005 Sep 28	GOM	0	JU		Hurricane	Major damage		
2005 Sep 28	GOM	0	JU		Hurricane	Major damage		
2005 09 28	GOM	0	JU		Hurricane	Rita - Beached, written off		
2005 09 28	GOM	0	JU		Hurricane	Rita - missing, sunk?		
2005 December 11	Buncefield UK	0	Oil storage terminal	Oil	Explosion			
2006 Apr 23	Norwegian CS	0	JU		Blowout	Shallow gas		

Date	Location	Fatalities	Installation	Chemical	Event	Description	Injuries	Cost (million USD)
2006 May 29	Java, Indonesia	0	LR		Blowout	Mud volcano, major release		
2006 Dec 06	Angola	0	SS		Sinking	Ballast problems		
2007 Apr 12	Atlantic Ocean	8	Ship		Sinking	Capsize, sunk		
2010 April 20	Deepwater Horizon, GOM	11	SS		Blowout	Fire and Explosion		
2010 October 4	Alka, Kolontár, Devecser, Hungary	9	Chemical	Alumina		Dam failure	100s	

Appendix C Questionnaire

Category	Question
OH&S-MS	The organisation manages safety with the same degree of expertise and to the same standards as other core business activities
	The current safety management system model lacks definition of its application during all the lifecycle phases of a development
	The total money and resources in general, allocated to various parts of the business is largely influenced by company culture.
	The safety culture in the organisation always means that safety gets the resources it needs to achieve safety performance targets
	Most senior management commitment to achieving improvements in safety performance is more rhetoric than substance
	Senior management commitment to achieving improvements in safety performance becomes more diluted/filtered as it cascades down the organisation
	There is effective workforce involvement in producing safety improvements, e.g. through safety committees
	The lessons that should have been learnt from major accidents such as Piper Alpha have been adequately captured and addressed by the organisation
	Given future challenges the organisation is more vulnerable to major accidents
	By applying the current approach to safety management the organisation can achieve both continuous and sustainable improvements in safety performance
	The Regulator has sufficient resources to carry out inspections that are frequent enough and in appropriate depth to discharge their duties
	The Regulator provides authoritative, proactive and accessible advice and is readily available to all personnel
	The Regulator uses its power of enforcement in a way that deters the organisation from taking intolerable risks or risks that should readily be reduced further
Project and Risk Management Risk Management	Since Piper Alpha, the goal-setting regulatory regime has improved safety performance more than if it had remained a prescriptive regime Excluding the HSE Department, the concept of Risk Assessment is well understood throughout the organisation, including main and subcontractors
	Excluding the HSE Department, the concept of Risk Assessment is well understood throughout the organisation, including main and subcontractors
	Risk assessment principles and tools are applied effectively throughout the organisations
	There are wide variations in the quality of risk assessments within the organisation
	The 'as low as is reasonably practicable' (ALARP) concept is applied on the basis that all measures/controls are initially implemented to eliminate or mitigate risks, unless it can be demonstrated there is a gross disproportion between the costs and the benefits

Category	Question
	Financial screening criteria, such as Net Present Value (NPV) do not adequately reflect risks and uncertainties because they are too prescriptive
	Risks that sit in the ALARP region (e.g. quantitative 1×10^{-3} to 1×10^{-6} or yellow region of the Risk Assessment Matrix, RAM), are generally considered adequate and no further action is seriously considered to assess whether further reductions are possible at relatively low cost
	There is sufficient benchmarking or cooperation between oil and gas companies to implement good, if not best, practice
	There is sufficient benchmarking or cooperation within the global organisation to implement good, if not best, practice
Project Management	I have been involved in Projects and believe I can answer questions about some aspects of safety in project management
	The requirements for managing safety risks during the design stages of a project are well understood
	There are no conflicts between the management of risks in design and other project aims and objectives
	In terms of cost-effectiveness and, when considered over the lifetime of a development, the design phase (from inception to detailed design inclusive) provides the greatest opportunity to eliminate or minimise risk
	During the design phase sufficient resources are provided to ensure that risks are adequately identified and mitigated to demonstrate an ALARP case, not just related to design, but when considered over the entire lifetime of a development
	During the design phase the project team has sufficient accountability to prevent the transfer of risks to subsequent lifecycle phases
	There are adequate KPIs for project teams, in the design phase, to measure safety deliverables to achieve lifecycle safety performance targets
	Project teams in general have sufficient operational experience to ensure that they can proactively minimise risks during the operational phase
	The project assurance process, and its implementation, are sufficiently robust to prevent intolerable and non-ALARP risks being carried over into subsequent project phases
	Projects targets are still driven by cost and schedule, and safety has a secondary influence
	When projects are fast-tracked, safety is not compromised
	The type and level of risk transferred from the design process to subsequent development phases is often unknown or not quantified
Measuring Performance	The industry is too focused on reactive (lagging/injurious based) key performance indicators (KPIs) and not enough on proactive
	The current approach to safety performance measurement provides an immediate and reliable indication of the level of performance
	The current approach to safety performance measurement ensures that those responsible for management of the risks understand and take ownership of the results, and take suitable and sufficient action to make improvements

Category	Question
	Informal reporting schemes such as safety suggestion, STOP, FOCUS, etc. are given adequate attention by the organisation in order to make a significant contribution in developing a proactive safety strategy
	The organisation is sufficiently aware that minor hydrocarbon releases may be an underlying symptom of a larger problem that has the potential to lead to major accidents.
	Employees are discouraged from reporting incidents or near-misses for fear of reprisal
	There is a significant under-reporting of incidents and near-misses
	Annual HSE plans have clear and transparent links to the previous year's performance to remedy past failures, prevent repetition, and provide a sound basis to achieve future sustainable improvements in safety
	The resources provided to effectively implement the annual HSE safety plan are always adequate to achieve success
Resilient Engineering	The concept of Resilient Engineering (RE) is well understood.
	Incidents are often prevented, not by policies and procedures, but by people who are flexible and competent enough to adapt to changing conditions
	Personnel are always given sufficient time to reflect on decisions to ensure avoidance of any unintended consequences
	The workforce is given sufficient time to provide adequate levels of checks and balances to proceed with their tasks safely (whether they choose to take it is not relevant here)
	The company emphasis on factors such as cost, schedule, production etc. has had, and continues to have, a detrimental impact on safety
	The employees (staff and contractors) have the means, and sufficient empowerment, to identify any increased potential for incidents or unnecessary risks and then prevent them
	People within the organisation have sufficient understanding of what is actually being practised and this is consistent with what senior management believe is happening
	The current incident investigation process provides sufficient information to understand the complexity of incident causation, particularly in root cause analysis
	Safety defences start to erode when under pressure, e.g. controls may be compromised due to cost, schedule, production pressures, etc.
	There is a perception within the organisation that when past safety performance has been good, this is taken as a reason for future confidence about the adequacy of current risk control practices
	Within the global or local organisation there is a fragmented approach to problem-solving that often clouds the big picture, i.e. there is not a shared risk picture when dealing with common hazards
	Once risk assessments are carried out, they are not always revised to reflect changing circumstances
	There is often a breakdown in communications and coordination between disciplines and departments that may contribute to errors and failures
	The organisation can respond flexibly and rapidly to changing demands, e.g. asset integrity issues

Category	Question
	Lessons learnt are adequately captured via the relevant management systems to ensure that similar errors or failures cannot be repeated in the future
	There are sufficient detailed audits on the organisation to ensure that there is adequate compliance with safety policies, procedures and practices
	The organisation has sufficient proactive key performance indicators (KPIs) to help identify whether it is drifting from a stable into a less stable state where risks may be increasing
	There are always sufficient competent and experienced people with adequate resources, e.g. time and money, in place to consistently deliver asset integrity
	There is a top-level commitment to achieving desired safety performance
	To achieve the desired level of safety performance, the organisation always proactively commits appropriate resources, e.g. money, people and time
	There is a 'Just Culture' in the organisation that encourages reporting of incidents but does not accept negligent behaviours
	There is a learning culture where there is no denial of adverse events but these are seen as positive and contribute to improvement
High Reliability Organisations	The concept of High Reliability Organisations (HROs) is well understood
	The organisation is wary of success since this tends to breed complacency
	Even minor incidents are treated as evidence of a more serious, underlying, problem, and these are considered as an early warning signal to take decisive action
	There is an over-simplification of incident information generated in the organisation that could result in the loss of some vital data and/or the information that is available is not processed effectively
	There is a suitable and sustained level of near-miss/near-hit/minor incident reporting in the organisation that allows the organisation to make proactive decisions to prevent recurrence or prevent escalation to more serious events
	There is an overload of incident information that leads to inaction due to the volume that requires assimilation
	There are sufficient competent and experienced people in the organisation to maintain consistency and continuity during periods of change
	Job rotation and using employees with non-typical job experience provides greater depth and more challenges in decision-making thereby allowing the organisation to cope better with the unexpected
Inherent Safety	In general, there is a 'silo' culture that inhibits openness and exchange of lessons learnt, practices and technologies
	The concept of Inherent Safety is well understood.
	The current risk control hierarchy uses the following approach consistently in the following order: a) Risk reduction by inherent safety b) Risk reduction by basic process control c) Risk reduction by pre-alarms d) Risk reduction by Instrumented Protective Function (IPF) e) Risk reduction by mechanical devices f) Risk reduction by other means

Category	Question
	Often designs are not inherently safe but tend to rely on procedural control
	Procedures are often incomplete or inaccurate
	Procedures often do not have sufficient detail e.g. that considers lessons learnt, the experience of users and their specific responsibilities
	Procedures are often not concise and contain information that does not contribute to work performance
	Procedures often have an inconsistent presentation/format therefore making them less comprehensible
	Hydrocarbon or other hazardous processes are always designed to minimise the maintenance burden
	Hydrocarbon or other hazardous processes are always designed to minimise intrusive instrumentation
	Hydrocarbon or other hazardous processes are always designed to minimise piping joints
	There is sufficient emphasis on process safety KPIs to achieve continuous and sustainable improvements in asset integrity
	Facilities are always initially designed to be unmanned, or to eliminate or minimise personnel exposure to hazards
	Designs always favour passive rather than active control systems
	Maximising inherent safety in design is seen as a cost-effective approach when considered over the lifecycle of the development (even if this requires greater initial investment)
	Safety studies include inherently safer design guidewords to ensure that they are properly considered in the decision-making process
	Senior management project sanction is conditional on the effective consideration of inherent safety in the design
	True lifecycle costs of projects (not just the cost of design, fabrication, installation and commissioning) are taken into account when assessing risks to enumerate the benefits of inherently safer design
	Concept selection is based on the ranking of various options with transparent safety criteria including the application of inherently safer design principles
	Applying inherent safety during design is likely to be compromised due to cost constraints, e.g. capital expenditure (CAPEX)
	Applying inherent safety during design is likely to be compromised due to competency and experience constraints of project personnel
	In the design of critical combinations and complex integrations of engineered systems, the design criteria for reliability, availability and maintainability (RAM analysis) is identified as a KPI to ensure desired design integrity, not just what can be achieved, but what should be assured
	Project teams always study past incidents associated with designs to minimise the potential of error/failure (hardware, software and human) by eliminating or mitigating the causes (immediate/root) of past problems.

Category		Question
Normal Theory	Accident	We mislead ourselves due to various pressures that the risks that are currently tolerated by the organisation are acceptable
General		What, if anything, do you think is required by your company (or the industry) to achieve continuous and sustainable improvements in safety performance?

Glossary

This is a glossary of some of the terms used in this research. Note that the sources used often have different definitions for the same term. Selection of the source was based on available definitions and relevant bodies.

Term	Definition	Note
Acceptable risk	Risk that has been reduced to a level that can be tolerated by the organisation having regard to its legal obligations and its own OH&S policy	1
Accident	See Incident below	2
As low as reasonably practicable (ALARP)	To reduce a risk to a level which is 'as low as reasonably practicable' involves balancing reduction in risk against the time, trouble, difficulty and cost of achieving it. This level represents the point, objectively assessed, at which the time, trouble, difficulty and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained.	2
Audit	Systematic, independent and documented process for obtaining 'audit evidence' and evaluating it objectively to determine the extent to which 'audit criteria' are fulfilled	1
Blowout	An uncontrolled flow of gas, oil, or other well fluids from the well.	3
Continual improvement	Recurring process of enhancing the OH&S management system in order to achieve improvements in overall OH&S performance consistent with the organisation's OH&S policy	1
Development well	A well drilled within the proved area of an oil or gas reservoir to the depth of a stratigraphic horizon known to be productive; a well drilled in a proven field for the purpose of completing the desired spacing pattern of production.	4
Downstream	When referring to the oil and gas industry, this term indicates the refining and marketing sectors of the industry. More generically, the term can be used to refer to any step further along in the process.	4
Hazard	Source, situation, or act with a potential for harm in terms of human injury or ill health, or a combination of these	1
Hazard identification	Process of recognising that a hazard exists and defining its characteristics	1
Health, safety and environmental (HSE) management plan	A description of the means of achieving health, safety and environmental objectives.	2
Hydrocarbons	Organic compounds of hydrogen and carbon whose densities, boiling points, and freezing points increase as their molecular weights increase. Although composed of only two elements, hydrocarbons exist in a variety of compounds, because of the strong affinity of the carbon atom for other atoms and for itself. The smallest molecules of hydrocarbons are gaseous; the largest are solids. Petroleum is a mixture of many different hydrocarbons.	3
Incident	Work-related event(s) in which an injury or ill health (regardless of severity) or fatality occurred, or could have occurred	1
Jacket	The lower section, or 'legs', of an offshore platform.	4
Kick	An entry of water, gas, oil, or other formation fluid into the wellbore during drilling. It occurs because the pressure exerted by the column of drilling fluid is not great enough to overcome the pressure exerted by the fluids in the formation drilled. If prompt action is not taken to control the kick, or kill the well, a blowout may occur.	3
Land rig	Any drilling rig that is located on dry land.	3
Natural gas	A highly compressible, highly expansible mixture of hydrocarbons with a low specific gravity and occurring naturally in a gaseous form.	3
Occupational health and safety (OH&S)	Conditions and factors that affect, or could affect, the health and safety of employees or other workers (including temporary workers and contractor personnel), visitors, or any other person in the workplace	1
OH&S management system	Part of an organisation's management system used to develop and implement its OH&S policy, and manage its OH&S risks	1

Term	Definition	Note
OH&S objective	OH&S goal, in terms of OH&S performance, that an organisation sets itself to achieve	1
OH&S performance	Measurable results of an organisation's management of its OH&S risks	1
OH&S policy	Overall intentions and direction of an organisation related to its OH&S performance as formally expressed by top management	1
Oil	A simple or complex liquid mixture of hydrocarbons that can be refined to yield gasoline, kerosene, diesel fuel, and various other products.	3
Operator	The company that has legal authority to drill wells and undertake production of hydrocarbons. The operator is often part of a consortium and acts on behalf of this consortium.	4
Organisation	Company, corporation, firm, enterprise, authority or institution, or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration	1
Petroleum	A generic name for hydrocarbons, including crude oil, natural gas liquids, natural gas and their products.	4
Performance criteria	Performance criteria describe the measurable standards set by company management to which an activity or system element is to perform. (Some companies may refer to performance criteria as 'goals' or 'targets'.)	2
Platform	An offshore structure that is permanently fixed to the seabed.	4
Preventive action	Action to eliminate the cause of a potential nonconformity or other undesirable potential situation	1
Proactive performance (Preventative risk management)	Also known as leading performance indicators. Leading indicators ...can be considered as measures of <i>process</i> or <i>inputs</i> essential to deliver the desired safety outcomes... Lagging indicators show when a desired safety <i>outcome</i> has failed or has not been achieved	See Ref for Reactive
Procedure	A specified way to carry out an activity or a process	1
Reactive performance indicators (reactive risk management)	Also known as lagging performance indicators. Lagging indicators are generated by a process of <i>reactive</i> monitoring, while leading indicators are the outcome of <i>active</i> monitoring. Reactive monitoring amounts to keeping track of undesired events, such as gas releases; active monitoring involves routine, planned testing and inspection [361]	See Ref
Reservoir	A subsurface, porous, permeable or naturally fractured rock body in which oil or gas are stored. Most reservoir rocks are limestones, dolomites, sandstones, or a combination of these. The four basic types of hydrocarbon reservoirs are oil, volatile oil, dry gas, and gas condensate. An oil reservoir generally contains three fluids—gas, oil, and water—with oil the dominant product. In the typical oil reservoir, these fluids become vertically segregated because of their different densities. Gas, the lightest, occupies the upper part of the reservoir rocks; water, the lower part; and oil, the intermediate section. In addition to its occurrence as a cap or in solution, gas may accumulate independently of the oil; if so, the reservoir is called a gas reservoir. Associated with the gas, in most instances, are salt water and some oil. Volatile oil reservoirs are exceptional in that during early production they are mostly productive of light oil plus gas, but, as depletion occurs, production can become almost totally completely gas. Volatile oils are usually good candidates for pressure maintenance, which can result in increased reserves. In the typical dry gas reservoir natural gas exists only as a gas and production is only gas plus fresh water that condenses from the flow stream reservoir. In a gas condensate reservoir, the hydrocarbons may exist as a gas, but, when brought to the surface, some of the heavier hydrocarbons condense and become a liquid.	3
Risk	Combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s)	1
Risk assessment	Process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk(s) is acceptable	1

Term	Definition	Note
Screening criteria	The values or standards against which the significance of the identified hazard or effect can be judged. They should be based on sound scientific and technical information and may be developed by the company and industry bodies, or provided by the regulators.	2
Semi-structured interview	A method of survey that takes a flexible approach and permits questions to arise in response to the dialogue. In a semi-structured interview, the interviewer will often put together a series of themes to be explored, rather than having a formal structure and fixed question set.	
Shutdown	A production hiatus during which the platform ceases to produce while essential maintenance work is undertaken.	4
Structured Interview	Fixed format interview in which all questions are prepared beforehand and are put in the same order to each interviewee. Although this style lacks the free flow of a friendly conversation (as in an unstructured interview) it provides the precision and reliability required in certain situations. Also called directive interview.	5
Upstream	The exploration and production portions of the oil and gas industry.	4
Well	The hole made by the drilling bit, which can be open, cased, or both. Also called borehole, hole, or wellbore.	3
Well control	The methods used to control a kick and prevent a well from blowing out. Such techniques include, but are not limited to, keeping the borehole completely filled with drilling mud of the proper weight or density during operations, exercising reasonable care when tripping pipe out of the hole to prevent swabbing, and keeping careful track of the amount of mud put into the hole to replace the volume of pipe removed from the hole during a trip.	3
Workplace	Any physical location in which work related activities are performed under the control of the organisation	1

Notes:

1 BS OHSAS 18001-2007

2 E&P Forum Guidelines for the Development and Application of Health, Safety and Environmental Management Systems Report No. 6.36/210

3 United States Department of Labor Occupational Safety & Health Administration – Glossary of Terms

4 Oil and Gas UK, Knowledge Centre - Glossary

5 Business Directory.com

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